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Sensor and Analysis Developments for Near-Earth Plasma Density Investigations

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This Technical Report has been reviewed and is approved for publication.

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13. ABSTRACT *(Maximum 200 words)*
With the progressive increase in solar activity, effects in the near-earth space environment (space weather) are becoming more intense and variable. They are manifested as increased plasma content of the ionosphere and protonosphere and as greater variability in these regions, with impacts on Global Positioning System (GPS) navigation, radio-wave communications, and other applications. This report summarizes research performed in the second year of a contract intended to (a) investigate natural variations in total electron content (TEC) and scintillation associated with solar activity and (b) observe artificially induced changes in the ionosphere by means of ground-based radio-wave emissions. The efforts for this second year included collection and processing of TEC data from the USAF Ionospheric Measuring Systems deployed at various sites, development of techniques for monitoring the electron content of the protonosphere, augmenting capabilities for providing near-real-time data for space-weather monitoring for the Space Environment Network Display, and coordinating and implementing development of diagnostic instruments for the High-frequency Active Auroral Research Program. Technical developments also were pursued to avoid the effects of artificial limitations imposed by the "Year 2000" problem and the similar "GPS Week Roll-over".

14. SUBJECT TERMS
High-frequency Active Auroral Research Program (HAARP), Radiowave scintillation, Global Positioning System (GPS), ionosphere, Space weather, Total electron content (TEC), Protonosphere (plasmasphere).

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Preface

This report summarizes work completed during the period from 1 September 1998 through 31 August 1999 on a project to investigate effects of the earth's ionosphere on transionospheric systems.

In addition to the authors, other contributors to the efforts described herein were NorthWest Research Associates (NWRA) staff members Charley Andreasen, John Begenisich, Elizabeth Holland, Guan-Shu Rao, James Secan, J. Francis Smith, and Tyler Wellman, and NWRA consultants William Gordon, Brett Isham, Spencer Kuo, Jens Ostergaard, John Rasmussen, and A. Lee Snyder.

We express our appreciation to TSgt. Theodore Denny of the Air Force Research Laboratory at Hanscom for his collaboration in support of the Ionospheric Measuring System (IMS) and the STEL 5010 data recovery; to Randy Hopkins of Raytheon for his on-site support of the IMS at Eareckson Air Force Station, Shemya, Alaska; to Dr. Joseph Heaton of the Defence Evaluation and Research Agency of the United Kingdom for his assistance in deploying the Real-Time Monitor (RTM) system in the Shetland Islands; to Sgt. Paul Collins for his on-site support of the RTM at Unst, Shetland Islands. We also express our appreciation for the opportunity to collaborate with Captain Kelly Law of the Air Force Institute of Technology (AFIT) on a study of the plasmasphere.

Acronyms and Initials

55 SWXS	55th Space Weather Squadron
AFIT	Air Force Institute of Technology
AFRL	Air Force Research Laboratory
APTI	Advanced Power Technology, Inc.
ARL	Applied Research Laboratory of the University of Texas at Austin
AWN	Automated Weather Network
CORS	Continuously Operating Reference Station
DERA	Defence Evaluation and Research Agency (United Kingdom)
DISS	Digital Ionospheric Sounder System
EMC	Electromagnetic Compatibility
FPI	Federal Prison Industries
FTP	File Transfer Protocol
GPS	Global Positioning System
HAARP	High-frequency Active Auroral Research Program
HFPL	HF-Enhanced Plasma Line
HP-UX	Hewlett-Packard UNIX (The UNIX refers to a computer operating system.)
IMS	Ionospheric Measuring System
IPP	Ionospheric Penetration Point
IPPDB	Ionospheric Penetration-Point Database
IPT	Integrated Product Team
ITS	Ionospheric Tomography System
NetCDF	Network Common Data Format
NIMA	National Imaging and Mapping Agency
NIMS	Navy Ionospheric Measuring System
NIPRNet	Non-Classified IP router network
NNSS	Navy Navigation Satellite System
NOAA	National Oceanic and Atmospheric Administration
NRL	Naval Research Laboratory
NWRA	NorthWest Research Associates
ONR	Office of Naval Research
PIM	Parameterized Ionospheric Model

PPP	Plasmaspheric Penetration Point
PRISM	Parameterized Real-time Ionospheric Specification Model
PSAB	Prince Sultan Air Base (Saudi Arabia)
RINEX	Receiver Independent Exchange (data format)
RTM	Real-Time Monitor
RTX	eXtension of the "RTM" (Real-Time Monitor) to collect 20-Hz data, replacing the Monitor ("M") capabilities of that program.
SAO	Standard Archiving Output
SCINDA	Scintillation Network Decision Aid
SCORE	Self-Calibration of Range Errors
SCSI	Small Computer System Interface
SEE	Simulated Electromagnetic Emission
SEND	Space Environment Network Display
SFG	Scale Factor Generator
STEL	Model Name for the 5010 GPS Receiver
SWIR	Short-Wavelength Infrared
SWN	Space Weather Network
TEC	Total Electron Content
TELSI	TEC and Scintillation (message format)
UPS	Uninterruptible Power Supply
USMC	United States Marine Corps
UT	Universal Time

SENSOR AND ANALYSIS DEVELOPMENTS FOR NEAR-EARTH PLASMA DENSITY INVESTIGATIONS

1. Project Objectives

The ionosphere can both disrupt and enhance the operation of military communication, navigation, and surveillance systems. For instance, the integral of plasma density along ray paths through the ionosphere (the "total electron content," or TEC) imposes range errors on signals received from satellites in the Global Positioning System (GPS). Indeed, GPS transmits two frequencies specifically for the purpose of correcting such error. The correction depends on reliable measurement of frequency-differential "pseudorange." Such corrections can be applied also to nearby or remote single-frequency receivers, a procedure that can be degraded by temporal changes and spatial gradients in TEC.

An objective of this project is to characterize the temporal changes and gradients in TEC as measured by means of GPS pseudorange and more precise measurements of frequency-differential carrier phase as the sun advances in its eleven-year activity cycle. To meet this objective, Northwest Research Associates (NWRA) is (a) operating, calibrating, and maintaining GPS-based equipment, including the Air Force Ionospheric Measuring System (IMS, AN/GMQ-35), at various locations and (b) processing and analyzing data obtained thereby.

It may be possible to enhance operation of some low-data-rate but high-priority communication systems by exercising a degree of control over ionospheric disturbance by means being investigated in the High-frequency Active Auroral Research Program (HAARP). Under HAARP, the Air Force Research Laboratory (AFRL) and the Office of Naval Research (ONR) are developing a facility in Alaska for upper-atmospheric, ionospheric, and solar-terrestrial research. An objective of this project is to contribute to characterizing processes triggered in the upper atmosphere and ionosphere by high-power radio waves to be transmitted from the HAARP facility, specifically as those processes relate to large-scale and km-scale irregularities in ionospheric plasma density and to radiowave absorption. Progress on HAARP topics is reported in Section 3.

2. GPS Topics

2.1 Standard Operations

Data files are processed, reviewed, and archived to tape at each of the deployed IMS sites at Ascension Island: Eareckson Air Force Station, Shemya, Alaska; Thule Air Base, Greenland; Croughton Royal Air Force Base, United Kingdom; and Otis Air National Guard Base, Massachusetts. Additionally, the same activities were performed for the fifth IMS, located at Hanscom AFB during its testing and qualification prior to deployment at Ascension Island. Tapes are catalogued for content and indexed for local storage upon arrival at AFRL each month.

The 15-Minute TEC data from Otis, Croughton, Shemya, (after 18 February 1999) and Ascension Island (after 30 March 1999) are reported by the IMS to AFRL by means of the Space Weather Network (SWN). The data can be plotted for each day to monitor the calibrations, data anomalies, and recent changes in the active GPS constellation. Such monitoring is conducted at a low level of effort following the decision in September 1998 to deactivate the IMS units at Otis, Croughton, and Thule. Only the Shemya IMS, which provides reference information for the COBRA DANE radar, is being provided with the full level of monitoring and calibration support, while the full operational status for the Ascension

Island IMS has not yet been implemented. A quick bias calibration is performed automatically on the Companion PC at each site, to facilitate detection of bias variations requiring re-calibration. These calculations are subject to some bias errors due to data anomalies, so operator judgment is required in evaluating the results.

A summary log is being maintained for the Otis IMS, the Croughton IMS, the Thule IMS, the Shemya IMS, and the Ascension Island IMS, primarily to monitor the duration of operations for each of the two UNIX computer systems in each IMS. The cause of system shutdown also is recorded in this log. A histogram of system operating-time durations, by month, is included in this summary log for each IMS. A summary table displaying the total percentage of operating time for each month and the number of occurrences of various outage causes also has been included. A Quarterly Status/Performance Report for the IMS sites was prepared, covering the months of July, August, and September 1998. This report includes the monthly performance statistics and outage causes for each deployed IMS, as well as other notable events and developments. These reports were subsequently discontinued, based on the available level of support.

The near-real-time data report transmissions from the field IMS units were reconfigured to arrive at the backup IMS monitoring computer, instead of the principal IMS monitoring computer, to avoid interference with operator tasks and reduce network conflicts. The display procedures for these data reports were revised to use the standard parameter files that are employed for other processing operations. This was a particular advantage in accommodating the increasing peak values of TEC that are being encountered with the rise in sunspot numbers.

The most recent bias calibration program, with additional elevation-weighting capabilities and provisions for utilizing external reference TEC values, was installed as the standard bias calibration program. The additional capabilities generally remain unused, so no immediate functional change in the bias calibration method occurred, but the additional capabilities now are available to handle anomalous situations.

Because of IMS data utilization by the COBRA DANE radar at Shemya, a regular schedule of calibrations is performed for that site so that the IMS is re-calibrated no less often than once every two weeks, and sooner if circumstances or data results indicate a need.

On 17 June 1999, the quick bias calibration for Ascension Island was changed to use the plasmasphere bias calibration method instead of the standard process used at the other IMS sites, which are all at middle or high latitude. This facilitates the daily review process by avoiding the apparent bias offset due to the TEC contribution of the plasmasphere. Transmissions from Ascension Island ended on 29 July 1999 due to network changes, but dial-up capability was restored on 30 August 1999. The IMS at Ascension Island was declared formally operational in mid-August, but a permanent connection to the SWN is required to implement this status.

GPS ephemeris files are retrieved from Holloman AFB on a weekly basis for use in determining the apparent sky positions of GPS satellites and the associated ionospheric penetration-point coordinates, which are used by the bias-determination process.

2.2 Scale Factor Generator

The TEC and Scale Factor log files from the Scale Factor Generator (SFG) program at Shemya for the period 12 August 1998 to 30 August 1999 were reviewed. Range correction tables were retrieved monthly from the 55th Space Weather Squadron (55 SWXS) electronic bulletin board until that distribution was discontinued in December 1998, after which these tables were acquired by special

arrangements with COBRA DANE personnel or 55 SWXS. These tables are used to determine the appropriate sunspot number for the ionosphere model incorporated into the Scale Factor Generator program. An identical version of the Scale Factor Generator program currently is operating on a computer for the operators there, as well as on the Companion PC for the IMS. Arrangements were made with the radar operators at Shemya to record scale factors determined from radar measurements into the TEC and Scale Factor log files, and these values also are reviewed. The radar scale factors can be compared directly to the Scale Factor Generator scale factors. A plot of corresponding values for the period 6 March 1998 to 25 February 1999 appears in Figure 1. Daily predictions of the hourly scale factors previously had been retrieved from the 55 SWXS bulletin board for future inclusion with these comparisons. For technical reasons, these scale factors have been unavailable since 9 November 1998.

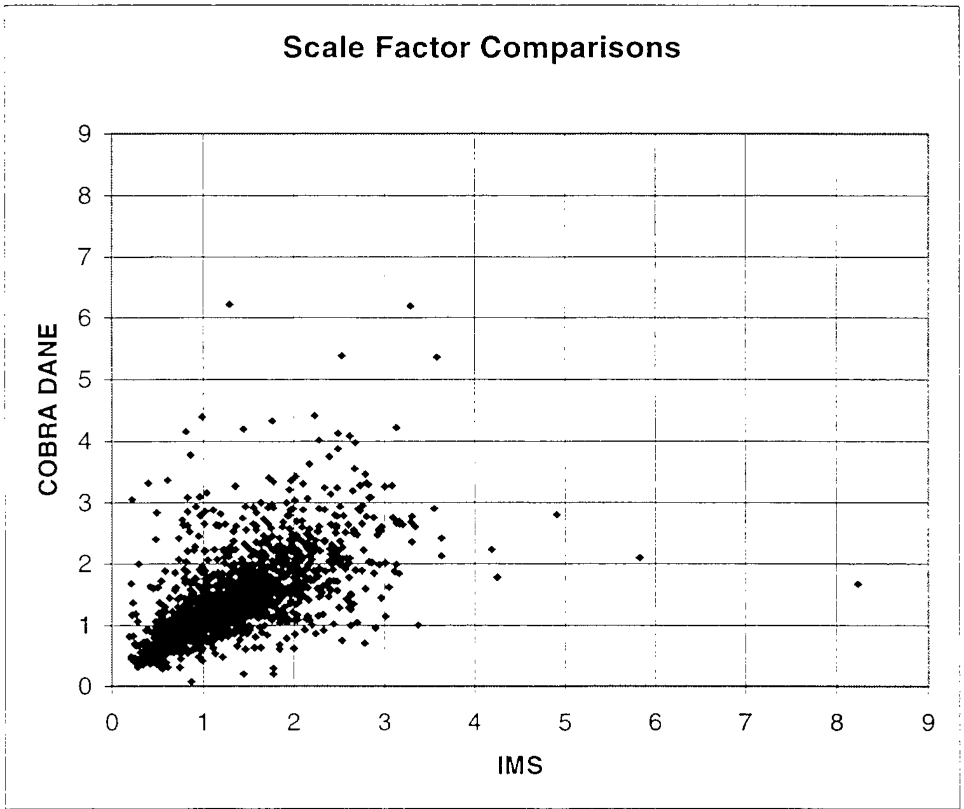

Figure 1. Ionospheric range-error scale factors, for measurements relative to the Bent ionospheric model, for the Shemya IMS and COBRA DANE radar, for the period 6 March 1998 to 25 February 1999, excluding days from 16-20 April 1998 for IMS maintenance.

2.3 Maintenance

The Companion PC at Shemya exhibited sporadic performance problems beginning in late July 1998 with occasional dial-up connection problems, becoming more frequent by late August, with the additional occurrence of interrupted processes and system restarts. No specific source for the problems was ascertained, but an examination by on-site personnel suggested a power-supply fan deterioration. An IMS-Net PC was sent to Shemya in mid-September as an interim replacement. The IMS-Net PC was installed by an on-site technician and functioned as expected, except problems were soon encountered

with the tape backup processing, which had functioned properly during testing at Hanscom. Following an investigation of possible causes, the tape drive in the IMS-Net PC was exchanged with the tape drive from the Companion PC, and normal operations were resumed. The Companion PC and the faulty tape drive were shipped back to Hanscom for repairs. This Companion PC arrived at Hanscom in mid-January, and was refurbished with a new power-supply fan, but remains without a replacement tape drive until additional repaired or replacement tape drives are available.

A regular maintenance visit to the IMS at Shemya was conducted from 30 April 1999 to 8 May 1999. Inactive equipment from previous investigations also was collected for shipment to AFRL at Hanscom.

Regular on-site maintenance was conducted for the Thule IMS following the relocation of that unit to the radar building in October 1998. A Windows-95 Companion PC that was retrieved from Thule is being tested using the Laboratory IMS, after conversion of the PC to Windows NT and associated hardware upgrades.

The Croughton IMS displayed symptoms of processor clock battery depletion in early June 1999, requiring manual setting of the processor time. The scripts for time recording and start-up time reset were installed to alleviate this problem. The Uninterruptible Power Supply (UPS) also was reporting errors at this time. The audible warnings were silenced after notifications from on-site personnel.

In mid-June 1999, the Otis IMS reported TELSI transmissions errors indicating that its associated Automated Weather Network (AWN) communications computer had shut down. On-site personnel could not restart this computer, apparently due to a hardware failure, so it was left powered off. TELSI messages from Otis still were transmitted using the SWN on a provisional basis, pending completion of the SWN migration from the AWN.

The UPS for the Otis IMS reported error signals in mid-July 1999, just prior to a site visit for routine maintenance by AFRL personnel. The signals indicate low battery levels, and were silenced after a subsequent recurrence and notification from on-site personnel.

2.4 Data Network Upgrade

Developments for the new SWN for data transmissions to succeed the current AWN continue, with prototype testing using the Laboratory IMS and its Companion PC at Hanscom.

In mid-September 1998, the network configuration for the IMS at Otis was revised to conform to NIPRNET utilization, so the associated network addresses were revised, by remote access, and operations were resumed in a normal manner. In late October 1998, NIPRNET connections were established for the Croughton IMS by 55 SWXS, so the network and processing configuration for that system was revised to use the additional capabilities. On 18 February 1999, the NIPRNET configuration for the IMS at Shemya was established, so the associated network addresses were revised by remote access. An exchange of network cables and Internet Protocol (IP) addresses was required for the two network boards in the IMS-Net PC at Shemya to attain operating status on the NIPRNET, but all other operations were sustained in a normal manner. The IMS units currently connected to the NIPRNET deliver TEC reports to Hanscom at 15-minute intervals using the SWN and provide TELSI messages to 55 SWXS through the SWN on a test basis.

Scripts utilizing pcANYWHERE were developed to acquire detailed IMS TEC data for all daily satellite passes using the SWN. These scripts supplement the dial-up data retrieval capabilities that are the current standard for all of the deployed IMS units.

Sporadic problems, primarily for the Croughton IMS, have been encountered with SWN file transmissions both at 55 SWXS and at Hanscom, with the apparent cause being an interruption of

connections during a file transmission. Secondary effects of this interruption are inaccessible files and disruption of normal file transmissions and processing. A change in the transmission procedures was implemented in March 1999 to alleviate some of these secondary effects, but the general reliability of the SWN must be addressed by 55 SWXS.

On 21 April 1999, FTP service into the AFRL network at Hanscom was terminated, with all FTP services being migrated to a separate server. Consequently, all automated data transmissions from the remote IMS units to AFRL were interrupted, and an alternative method was required to re-establish automated transmissions. The appropriate computer account and directory structure was established on the new FTP server, and each of the remote IMS units was modified to transmit its data to that system. To maintain the full data monitoring capabilities implemented at Hanscom, a secondary process was established to monitor the arrival of new data files at the AFRL FTP server and to transfer these files to the standard IMS data collection system. This processing has worked well since it was established on 30 April 1999.

Temporary settings were established at the IMS field sites to halt network transmissions to AFRL at Hanscom in late July 1999, while network changes were being performed at AFRL. Transmissions were resumed later the same day, and various system configuration changes associated with the local network change were completed.

Preparations were initiated to accommodate the establishment of a network firewall at Hanscom. This action, and a change of Internet service provider for the laboratory, is scheduled to occur in early September 1999. The epilogue for this event is provided in the "Data Network Upgrade" section of 0078 QSR #9, which covered the quarter following this annual report. The firewall implementation and the change of Internet provider were endured and (mostly) overcome, as described in that section.

2.5 Laboratory IMS

Laboratory working models of an IMS, without the enclosure or redundancy of the fielded IMS units, have been constructed at Hanscom for development and testing.

A second spare Apollo processor, of the same type as used in the IMS units, was configured for testing with an augmented swap space (virtual memory) matching the assignments in the deployed IMS units instead of the HP-UX default amount. The augmented swap space improved system performance, but initially did not eliminate occurrences of system shutdown without error reports. This situation now is attributed to a swap space problem for the network connections and was resolved by a change in the configuration settings. This processor is being used for final testing of the "GPS Week Rollover" remedy, UNIX script revisions, and development of modem interface configurations for replacement modems.

A recurrent problem with the Informix database for GPS data was encountered during testing. The problem was investigated and resolved, but it exhibited some similarities to the rare database problem encountered for the Thule IMS.

This laboratory IMS shut down in mid-August 1999, apparently for a normal error condition. This system is not equipped with an automated restart capability and was restarted manually, but the disk containing the operating scripts and data storage areas was not accessible so the IMS data collection software would not operate. This situation is still being examined.

A second laboratory working model IMS was established for the newer Visualize processor using a separate data storage disk, receiver, UPS, and temperature sensors from those used by the Apollo system. Tape drives were determined to be non-essential for operation of the IMS software, so none were included for this system.

This second laboratory-working model IMS was investigated to overcome problems in initializing the custom IMS application software. Problems particular to this version of the operating system were overcome so a reliable start-up of the IMS application software now is achieved on a regular basis, except in one circumstance. This circumstance was found to be common with the Apollo processors and their version of UNIX, but was not readily apparent because most of these systems have an automated restart capability in a dual-processor environment, avoiding most such occurrences and masking their rare appearance. If the entire IMS database is older than several days, the database routines fail on the initial restart but will succeed on a subsequent immediate restart. The automated restart capability generally prevents long dormant periods for the IMS database, which is on the shared disk for the two UNIX processors, and, even if a long dormancy occurs, the immediate swap from one system to another after a start-up failure provides for recovery from the error. Further investigation of this condition will be pursued.

An auxiliary UPS for the Companion PC was delivered to Hanscom for evaluation. This UPS is intended for installation within the IMS rack, as configured for Ascension Island, where the Companion PC is installed inside the rack and operates on power provided by the primary IMS UPS. Because the command and communications port of the primary UPS is connected to the UNIX processors, the Companion PC has no information regarding an imminent UPS power shutdown. The communications port of the auxiliary UPS can be connected to the Companion PC and provide notification when its power source is absent, allowing the Companion PC time to perform a controlled shutdown and reducing possible system problems. This auxiliary UPS is scheduled to be installed in the Ascension Island IMS during the next maintenance trip.

2.6 Software Development

The IMS software received from Charles Stark Draper Laboratory was reviewed for information regarding IMS operations and functionality, with special concern for "Year 2000" effects and the "GPS Week Rollover," expected on 22 August 1999. The Software Development System for the IMS also was utilized in this effort. A structural outline of the IMS Ada code was developed and annotated to indicate the review status of the IMS source code and areas of potential concern for either the "Year 2000" effects or the "GPS Week Rollover." All of the Ada modules have been reviewed with the exception of those associated with the AWN transmissions, which will become obsolete when the transition to the SWN is completed.

Software modifications for validation testing for the "Year 2000" and "GPS Week Rollover" effects have been performed. Based on a suggestion by AFRL personnel, these tests were conducted by introducing an offset to the GPS Week value acquired from the receiver, effectively advancing the date to any desired future date. A suitable choice of the code module for implementing this offset allowed the date setting to be effective for both the UNIX operating system date and time comparison and the Informix database storage. The UNIX operating system (HP-UX version 9.01) was found to be operational for dates up to 2036. Critical dates from the "GPS Week Rollover" through the year change into 2001 were simulated and tested. Information and materials were provided to AFRL personnel for a "Year 2000" status and certification review conducted at Hanscom in November 1998. Demonstrations of "Year 2000" operation of the IMS also were provided. Except for occasional tests, primarily conducted on the first Laboratory IMS, normal operations with the delivered Ada software were resumed for the fifth IMS.

Documentation describing the IMS software configuration management procedures was prepared, preparation of the revised Ada module for resolution of the "GPS Week Rollover" was completed, and the revised programs were installed on the IMS at Otis on 20 April 1999. The performance of the IMS at Otis

was monitored for several weeks, and it was decided to institute the second phase of the field testing by installing the revised programs on the IMS at Croughton. The IMS at Croughton utilizes AWN protocols different from those at Otis, but the two sites together completely utilize the custom IMS Ada software. The revised Ada modules for resolution of the "GPS Week Rollover" were installed on the IMS at Croughton on 2 June 1999. The performance of the IMS at Croughton was monitored for several weeks, and it was decided to complete the field deployment by installing the revised programs on the remaining IMS units at Shemya, Ascension Island, and Thule. The revised programs were installed on the Shemya IMS by 28 July 1999, but poor telephone connections to Thule thwarted the installation until 20 August 1999, while telephone and network access to the Ascension Island IMS were unavailable after 29 July 1999. Consequently, on-site personnel at Ascension Island were requested to unplug the IMS on 20 August 1999, triggering the UPS to invoke a controlled shutdown of the system. Monitoring of the IMS units following the "GPS Week Rollover" on 22 August 1999 indicated that all systems with the revised programs operated during and after the week transition.

The IMS Ada modules were reviewed to determine the parameters governing the generation of TELSI messages. This effort was pursued both as part of an ongoing investigation into a sporadic problem of missing TELSI source data and a potential development to increase the frequency of IMS data reports to 55 SWXS. No distinct resolution of the problem of missing TELSI source data was achieved, so the investigation will need to encompass the Matlab computational functions and Informix database operations. The Ada code parameters governing the time interval for reports were identified, but the Matlab scripts and Informix database need to be checked for associated parameters.

Further revisions for post-processing and analysis programs were incorporated to address "Year 2000" issues. These revisions have been developed with flexibility in allowing the programs to be used for both existing data sets with two-digit year identifiers or newly-created data sets with four-digit year identifiers. Associated batch files were modified to allow for specification of four-digit years with possibilities for interactive specification by the user.

A cross-reference table was prepared, displaying the component programs and batch files used within all of the standard processing and analysis batch files for GPS studies. This table was adapted to an alternative format allowing the inverse association to be displayed, so that all batch files referencing a specified program or batch file can be determined easily.

In preparation for the relocation of the Thule IMS from a remote building to the radar building at Thule and its anticipated use for radar support, a program was developed to plot the GPS TEC measurements as equivalent range errors on a sky projection map. This program was demonstrated to on-site personnel at Thule during the IMS relocation activities conducted in October.

The program that monitors file creations or transmissions for various processing applications was modified to keep proper count of multiple day transitions, while avoiding false day transitions from small clock time adjustments. This program also is used to detect hung processing operations, based on an abnormal delay in the appearance of a file, and initiate appropriate remedial actions, including a complete system restart. The revised version of this program is being distributed to all of the fielded GPS TEC systems.

Programs that generate data tabulations from ionosphere or plasmasphere databases were modified to generate distinct tabulation columns, avoiding interpretive problems for subsequent processing programs.

2.7 Thule Operations

NWRA and AFRL personnel traveled to Thule during the first half of October 1998 to relocate the IMS from a remote building to the radar building. For this relocation, the IMS was transported as a unit, rather than being disassembled and reassembled, and, after some initial equipment delays, this transfer was accomplished without incident. A custom antenna mount was installed on the roof of the radar building, with suitable fastening to withstand the high winds that can occur at that site. The Ashtech GPS antenna was fastened to this mounting, without the usual IMS antenna housing, and a low-loss antenna cable was installed between the antenna and the IMS receiver, located several stories below. Normal operations were resumed after a hiatus of about ten days, including the recalibration of the IMS for the new antenna cabling and the transmission of TELSI messages on the AWN.

In addition to the IMS relocation, the Windows-95 Companion PC at Thule was exchanged for a Windows NT Companion PC capable of functioning on the proposed SWN. An IMS-Net PC also was provided as an inactive spare. The IMS Ashtech receiver was exchanged for another Ashtech receiver with the 1G02 version of the firmware, permitting the original Ashtech receiver to be prepared for shipping for a hardware and firmware upgrade. The Windows-95 Companion PC retrieved from Thule was reconfigured with additional components and Windows NT, and is being prepared as a spare Companion PC for SWN operations.

Preliminary coordination for possible future NIPRNET connections to the IMS also was conducted during the relocation trip, prompted by the fortuitous arrival of technical personnel at Thule. The necessity of a NIPRNET connection is currently uncertain, pending the new role assignments for the IMS units, but a near-term role at Thule for ionospheric environment studies is among the possibilities.

The Companion PC at Thule was performing erratically on 22 March 1999, and a preliminary diagnosis of a failed power supply fan was made, in conjunction with reports from on-site personnel. The on-site IMS Net PC replaced the Companion PC, and normal operations were resumed. Arrangements were initiated to have the Companion PC shipped back to Hanscom for repairs.

Data from the Thule IMS for January 1999 were copied to local disks from tape and transcribed to CDs in anticipation of support requirements for the campaign in Greenland conducted that month. A preliminary review of selected data was conducted, in conjunction with AFRL personnel.

2.8 Otis Operations

On 1 February 1999, the single Otis IMS processor rebooted with an incorrect date (2 April 1999) because the clock battery had expired. The correct time was set manually several times by remote access, but the incorrect time appeared at each system restart. Developments were completed for resolving this situation using an updated disk-file time reference and some script additions for the system startup, and the Otis IMS was reactivated on 3 March 1999. One detrimental side effect of resetting the time during system startup is that the visual user environment interface does not complete its initialization, but this is not a problem unless there is an on-site user with a need to access the system console. A resolution for this problem is being pursued.

2.9 Anomalous Biases

The phenomenon designated as "anomalous biases" is an apparent significant bias shift for a single satellite for a single passage across the sky. Negotiations between AFRL personnel and the receiver manufacturer Ashtech resulted in arrangements to acquire a receiver firmware upgrade (version 1I11) for installation in some of the available IMS receivers and to ship other receivers back to Ashtech for a hardware upgrade and firmware installation. One spare Ashtech receiver was selected for firmware

testing at AFRL, being a sufficiently recent model to allow local installation of the firmware, which was acquired from Ashtech through the Internet. The performance of this receiver was checked prior to the firmware upgrade, using the Laboratory IMS, and its operation after the firmware upgrade was checked again using the Laboratory IMS, for a period of a week. The upgraded receiver then was installed in the IMS at Otis on 20 August 1998, with the data subsequently being monitored as a regular part of IMS operations. More than eight weeks passed without any occurrences of an anomalous bias, but further firmware installations were delayed by the assignment of technical personnel for the Thule relocation effort. An anomalous bias event was detected for Otis on the first working day following the Thule relocation trip. Subsequent discussions between AFRL personnel and Applied Research Laboratory (ARL) personnel supporting the National Imaging and Mapping Agency (NIMA) Ashtech receivers indicated that the 1I11 firmware upgrade had failed to resolve the problem for NIMA. Further firmware upgrades therefore were postponed indefinitely.

2.10 Additional Developments

Further refinements for a revised physical configuration of the components within the IMS enclosure were conducted, using the fifth IMS at Hanscom. In this configuration, the Netblazer communications processor and the original video monitor have been removed, with the video monitor being replaced by a flat-panel monitor supporting both the UNIX and Windows processors. A special supporting shelf for field use of the flat-panel monitor was designed for construction by AFRL. Both the Companion PC and the IMS-Net PC are installed within the IMS enclosure with a shared membrane keyboard and touchpad mouse. Some of the original modems for dial-up to the UNIX systems were replaced by smaller high-speed modems, but the AWN modems were retained, although these will become expendable when the SWN implementation is completed. This configuration alleviates the additional floor space or height requirements of the Companion PC and IMS-Net PC while retaining all of the functions of the current IMS configuration. This configuration performed well for laboratory work and was designated as the deployment configuration for the fifth IMS. This configuration is displayed in Figure 2.

During configuration preparations for the fifth IMS, the system disk for the System-A processor exhibited an apparent failure. Further examination, utilizing one of the spare Apollo processors, indicated that the disk was intact but appeared to have lost its bootstrap capability. A spare Apollo processor was configured to replace the System-A processor, but further problems were encountered. In addition, a Matlab license was required for the replacement processor. As a contingency for the spare processor difficulties remaining unresolved, the System-A processor from the Otis IMS was retrieved on 20 January 1999, for possible reconfiguration as the System-A processor of the fifth IMS. During this trip to Otis, the Ashtech receiver (with version 1I11 firmware) was exchanged for a receiver with version 1G02 firmware, because the Otis receiver had experienced an irrecoverable firmware failure on 11 January 1999. The Hanscom System-A processor problem was resolved by the discovery of a misaligned pin for the SCSI connection, so the original processor was restored to operation in the fifth IMS.

The Ashtech receiver retrieved from Otis in January 1999 with failed firmware was returned to AFRL after repairs by Ashtech and has been installed in one of the local GPS systems for testing. Two other Ashtech receivers with hardware or firmware upgrades also are being tested.

Provisions for plotting the difference between maximum and minimum vertical TEC values over 15-minute intervals were incorporated into the program that displays the 15-Minute data reports from the IMS. This additional display was utilized in conjunction with plots of the standard deviation in vertical TEC to conduct a survey of 1999 data from the Shemya IMS for cases of significant variability. Several cases of significant temporal slant TEC variations were identified. Plots and associated summary tabulations were presented for further review by COBRA DANE support personnel.

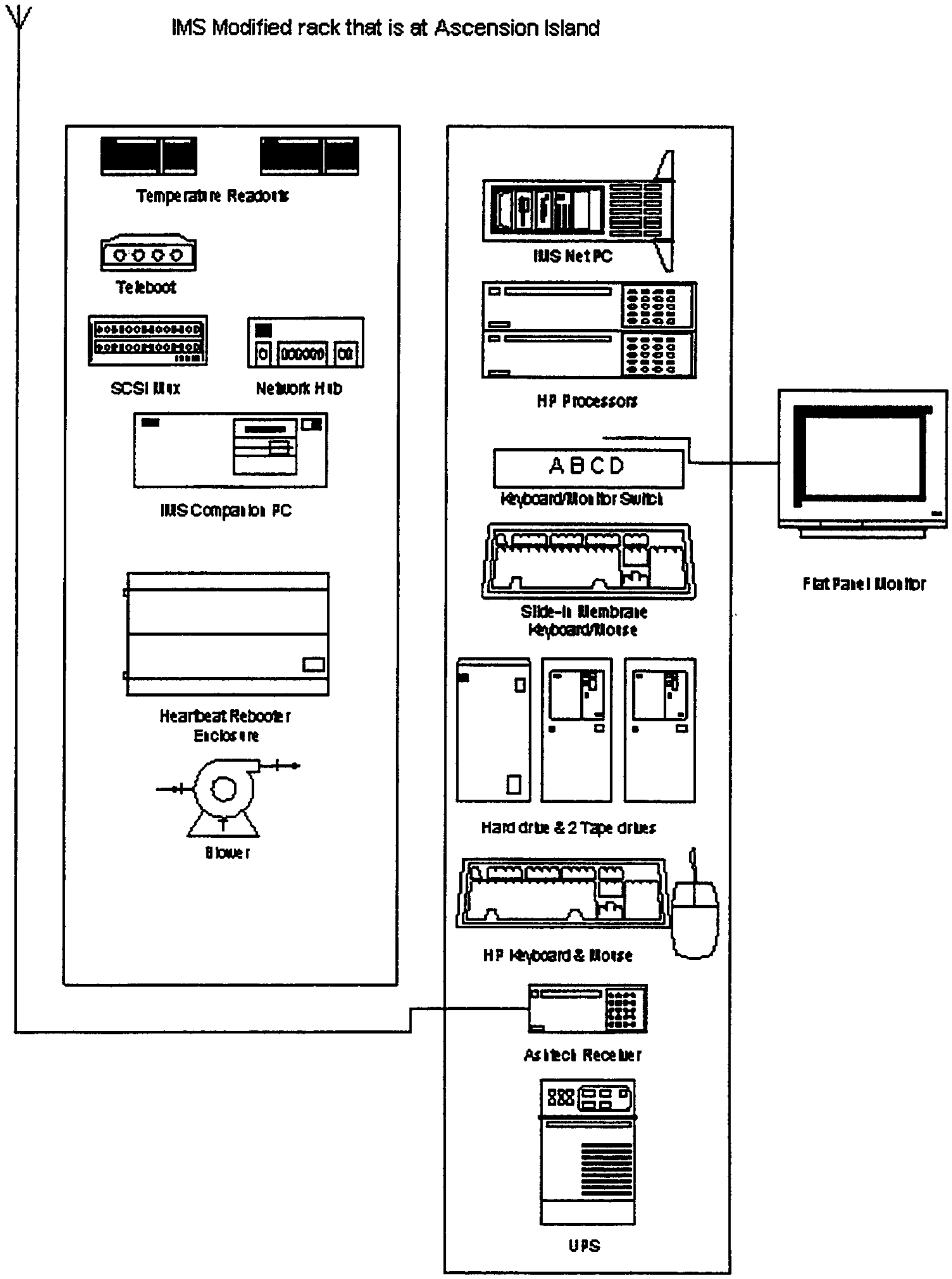

Figure 2. Deployment configuration of fifth IMS.

Provisions for extended precision in tabulations of Differential Carrier Phase were incorporated into data processing software for the IMS, and further plots of the 2 Hz IMS data from Ascension Island were generated based on these tabulations. Intensity and phase spectra were generated for a 512-second interval at about 22:00 Universal Time on 6 April 1999. The overall excursion in phase TEC for this period was about 24 TEC units, which was de-trended using a cubic polynomial to produce a residual variation of about 2 TEC units and a spectral slope of about –3, over the frequency range 0.1 Hz to 1.0 Hz. (See Figure 3.)

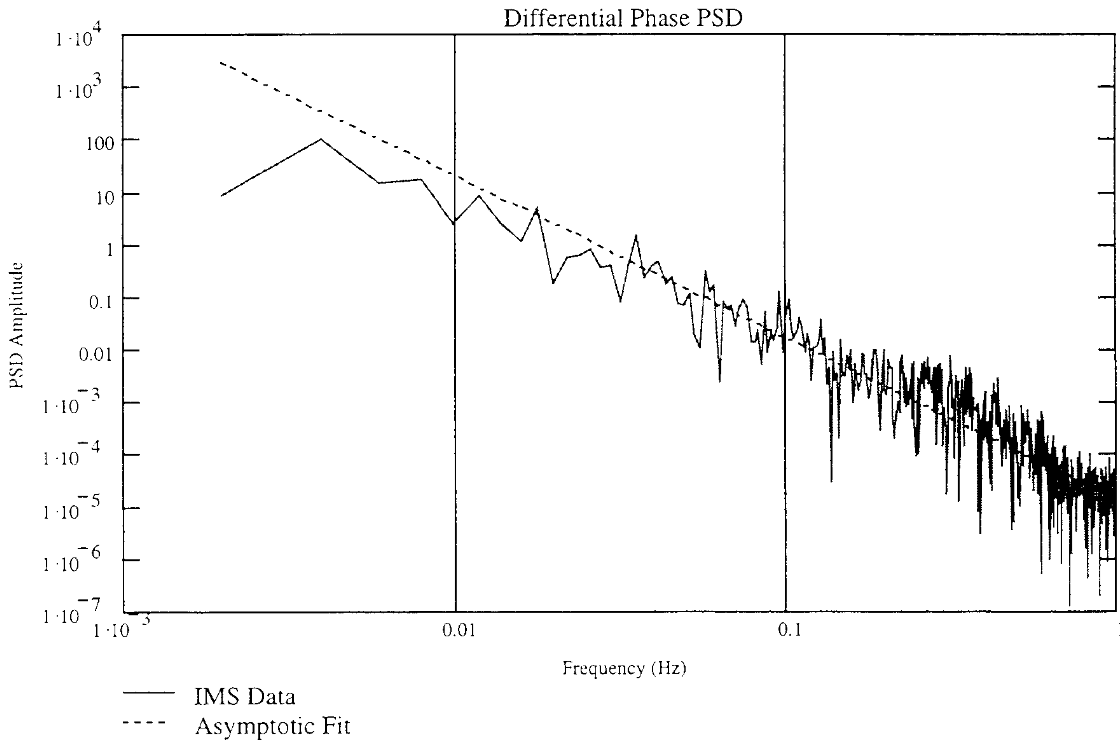

Figure 3. Power spectrum of 2-Hz differential phase from the Ascension Island IMS on 6 April 1999, with a power-law fit over the frequency range 0.1 Hz to 1.0 Hz. The slope of the fit is –3.1.

2.11 Alternative Data Evaluations

Data collected at Ascension Island by a portable RTM system were processed for TEC profiles and signal intensity, with a supplementary survey of the signal intensity data for scintillation occurrences. Data files were recovered for most of the data collection period from 23 January 1998 to 10 April 1998, with a total of nine days without coverage and several days with only partial coverage. A preliminary examination of the GPS phase data was conducted, but the set of programs and procedures for processing these data remains to be developed.

Version 2.5 of the RTM software was acquired from Applied Research Laboratory at the University of Texas in late 1998, and testing was begun. Results were found to be satisfactory, and this version of the RTM program was installed on the RTM system deployed to the Shetland Islands by remote dial-up connection in early December 1998.

Prospects for measurements from a radio beacon to be flown aboard a rocket launched from Kodiak Island prompted a reactivation for the ITS-10 receiver at Hanscom. Components were retrieved from storage and from rooftop installations, and performance testing was begun to determine the operating condition of the receiver. Plans for a concurrent GPS receiver deployment with the ITS-10 were developed. This effort was abandoned when the radio beacon was eliminated from the rocket payload at a time when some problems with the ITS-10 operation became apparent.

Two RTM systems are being operated at Hanscom for development of data collection and processing methods, with particular application to the data-collection systems deployed at the Shetland Islands and HAARP. Various software, script revisions, and additions are tested on these systems before use on the deployed field systems. Among the features tested here were new provisions for log file maintenance, additional provisions for data file maintenance, and refinement of the File Monitor operations.

Data from one of these systems, together with archival data from the summer of 1998, were used to evaluate possible remedies for the GPS "ghost" problem in which a spurious satellite signal is reported. A review of archival data from the summer of 1998 detected no "ghost" occurrences in circumstances in which some were expected, but the use of extra antenna cabling connectors may have provided sufficient signal reduction to avoid the problem. Quantifying the amount of signal reduction required to eliminate "ghosts" remains part of the investigation. This investigation was conducted jointly with AFRL personnel.

Data from the Croughton IMS and three European stations of the International GPS Service network (Kootwijk, Netherlands; Westerbork, Netherlands; Brussels, Belgium) for 2 April 1998 and 6 April 1998 were processed to provide reference TEC values for a utilization and validation study for the Parameterized Real-time Ionospheric Specification Model (PRISM). Provisions were developed for generating reference input TEC data for PRISM from post-processed and re-calibrated TEC databases. Results from these tests were compared to previous tests that used real-time input, which contains significant effects from multipath, and a greater consistency between the reference TEC data and the PRISM output was evident. AFRL personnel presented these results at the May 1999 Ionospheric Effects Symposium.

A preliminary assessment of the requirements for a generic GPS data station has been conducted. The core requirements of such a station would be the common attributes of the IMS and RTM units currently deployed, with sufficient flexibility in the implementation so that the resulting station could perform the essential functions of an IMS. Further definition of this entity is required.

Previous investigations into TEC calibrations for single-frequency GPS systems were reviewed, to evaluate areas for future investigation and potential benefits in comparison to the transmitted GPS TEC model. The role of the bias calibration technique incorporating the plasmasphere also was considered. The preliminary assessment is that the error for the calibrated single-frequency TEC is at least as large as the error in the GPS TEC model at mid-latitudes, but an error of a similar magnitude in equatorial regions generally would be less than the GPS TEC model error. The ability to achieve this level of error for the equatorial regions will depend on the successful development of the bias calibration accommodating the plasmasphere.

2.12 International Collaborations

An RTM system was shipped to the United Kingdom and was delayed by Customs for about a month before being delivered to the Defence Evaluation and Research Agency (DERA) in Malvern, England. The computer system, receiver, and antenna were assembled there for familiarization and testing, including remote dial-up. Personnel at Defence Evaluation and Research Agency provided power and telephone adapters for this assembly stage, obviating the need to ship adapters acquired at Hanscom. After a brief test period, the components were re-packed and shipped to Unst in the Shetland Islands, where they were re-assembled and activated. Initial dial-up connections were established and sufficient data were retrieved to perform a GPS bias calibration. Limitations of the serial port data rate forced a revision of the data sampling interval from one second to two seconds, and coordination with on-site personnel were required to restore the data sampling interval to one second, because configuration commands on the receiver panel must be invoked. Data retrieval and remote monitoring of this system from AFRL is continuing for its period of operation.

The detailed data are time sequences of signal strength and phase for each of the two GPS frequencies, while the time-average data records, at a sampling rate of once per minute, consist of differential group delay, differential carrier phase, and intensity scintillation index. On 2 December 1998,

with assistance from on-site personnel, the detailed data-recording rate was increased to 1 Hz. The detailed data are intended to monitor scintillation and clutter phenomena, and the average data are intended to monitor TEC and survey the scintillation occurrences. This system was operating at Unst, in the Shetland Islands, until mid-December 1998, when a severe storm caused some damage to the GPS antenna. A spare antenna was shipped by AFRL to the United Kingdom, and was installed by on-site personnel on 12 April 1999. Data collection was resumed, but remote dial-in to the system from AFRL was not possible, initially due to telephone line problems and subsequently due to failure of the internal modem for the PC. A new modem was ordered for shipment to the site, but occasional connections were established by using an external modem provided by on-site personnel. The tape drive subsequently was found to be inoperative and an alternative process of disk archiving was established using the large spare hard drive installed in the computer. Even with file compression, disk space is being used at a rate of about 10 MB per day, and the available space will be exhausted before the end of December. Consequently, a replacement computer has been configured for shipment to Unst. This system is being tested, and refinements in the near-real-time processing are being implemented.

The inoperative GPS antenna that was replaced at Unst was received at AFRL and examined. The amplifier section was found to be severely corroded with corrosion impinging on the circuit board. For this model antenna, the amplifier section is removable. A replacement amplifier was ordered from the vendor. This amplifier was tested with the antenna and an available Ashtech receiver, with satisfactory results.

The replacement computer for Unst was utilized for demonstrations of the new 20-Hz Ashtech data collection software developed by the Applied Research Laboratory . This software utilizes latent capabilities in later versions of the Ashtech receiver firmware to collect dual-frequency phase data and single-frequency (L1) intensity data in a binary format which can be translated into a text tabulation using a post-processing program also provided by Applied Research Laboratory . The 20-Hz data collection capability was provided both as a stand-alone program (RTX) and also as part of an upgraded RTM program. Both programs contained provisions to handle the "GPS Week Rollover," which occurred at 00:00 Universal Time on 22 August 1999. Continued testing is being performed on the Unst replacement computer, especially with regard to data archiving provisions because the 20-Hz data accumulates at a rate of about 10 MB per hour.

The upgraded RTM software also was installed on the deployed system at Unst (with the 20-Hz data collection deactivated) to resolve the "GPS Week Rollover" problem, but the RTM system at Unst now occasionally lapses back to the previous week. It is not clear whether this is a problem intrinsic to the RTM program or an effect from one of the GPS satellites after the Week Rollover.

A third RTM system is being developed for deployment to Qaanaaq, Greenland, just north of Thule Air Base, for a campaign occurring in mid-September. This system will utilize the 20-Hz Ashtech data collection in addition to the standard TEC data collection. Additional post-processing software also will be developed for analysis of the data from this campaign.

2.13 Plasmasphere Investigations

In mid-September 1998, discussions were conducted with AFRL personnel and a student from the Air Force Institute of Technology (AFIT) about methods for determining TEC contributions by the plasmasphere, based on preliminary techniques previously published (Bishop et. al., 1997). Preliminary investigations were conducted for a single-station technique, using the Parameterized Ionospheric Model (PIM) to remove the ionosphere contribution, and a two-station technique, using a common ionospheric

penetration point for stations along a meridian to eliminate the ionospheric contribution. The two-station technique was selected.

Procedures for acquiring data from the National Oceanic and Atmospheric Administration Continuously Operating Reference Station (CORS) distribution system were demonstrated for the AFIT researcher, as were the associated procedures for processing and calibrating the TEC data. Post-processing capabilities were developed using existing programs, spreadsheet database queries, and spreadsheet calculation and plotting capabilities. Similar techniques for re-formatting and utilizing PIM results also were demonstrated. Preliminary data results were examined to assist in the resolution of anomalous situations and to verify an appropriate use of the procedures.

Discussions with the AFIT researcher were conducted throughout the remainder of the two-station plasmasphere investigation, particularly with regard to features of the bias calibration method, and also concerning the Gallagher plasmasphere model in PIM and preliminary assessment of the data analysis. This research project concluded with a successful Masters thesis presentation by the AFIT researcher in early February 1999.

2.14 GPS Bias Calibration Methods

Investigations and software development for an improved technique for GPS bias calibrations were resumed. Based on previous studies, a simple geometrical representation of the plasmasphere was developed, and algorithms were implemented for determining intersections between arbitrary ground-based lines-of-sight and the designated plasmasphere boundaries. These algorithms were incorporated into a program to generate plasmaspheric penetration point (PPP) databases, defined as an extended form of the ionospheric penetration point (IPP) databases used for the current bias calibration technique, commonly referred to as SCORE (Self-Calibration Of Range Errors).

Because the structure of the plasmasphere is governed by the earth's magnetic field, the plasmaspheric penetration point databases are defined in terms of magnetic coordinates using an earth-centered dipole field (Jursa, 1985). The orientation of this dipole field is determined to produce a magnetic coordinate system corresponding to corrected geomagnetic coordinates in the vicinity of the observational site. In addition to the ionospheric penetration point coordinates and local time, the plasmaspheric penetration point database contains latitude, longitude, and radius values for the two possible intersections of a line-of-sight with the simple representation of an L-shell that is bounded below by a spherical shell lying above the main ionospheric region. The plasmaspheric penetration point database also contains the line-of-sight distance contained within the modeled plasmasphere L-shell domain and the cosine of the line-of-sight zenith angle at the lower plasmaspheric penetration point. These latter two parameters were included based on plasmasphere studies using the Gallagher plasmasphere model (Gallagher, 1988) incorporated into PIM (Daniell et. al., 1995), and aid in characterizing the plasmaspheric TEC contribution along the line-of-sight. In circumstances where the line-of-sight does not intersect the modeled plasmasphere domain, flag values are used in selected variables.

The planned extension to SCORE incorporates an additional correction term in the conversion from raw (biased) slant TEC measurements to equivalent vertical TEC measurements. This additional term contains an unknown amplitude factor indicative of the plasmaspheric density and a known coefficient derived from the geometrical plasmasphere model. Correlations of different TEC measurements for common ionospheric penetration points is expected to allow determination of the unknown bias values and the plasmaspheric density factor. Implicit in this formulation is the assumption that the plasmaspheric

TEC contribution is nearly constant on a diurnal basis, but this assumption appears to be justified by a recent study (Lunt et. al., 1999).

Some refinements in the simple plasmasphere model, and its associated line-of-sight TEC contribution, were implemented with provisions for flexibility in changing the parameters characterizing the plasmasphere structure and its density distribution. Additional evaluation and display programs were created. Some technical problems associated with the plasmasphere penetration-point determinations were resolved, with the necessity of eliminating isolated data samples for which penetration points could not be calculated. These appear to occur at the cusps of the plasmasphere model, where the upper and lower plasmasphere penetration points are too close together to be resolved separately.

Initial investigations were conducted using simulated ionosphere and plasmasphere data produced at the University of Wales at Aberystwyth. This data set provided known values for the ionospheric TEC, the plasmaspheric TEC, and the combined satellite and receiver biases, but was for a northern mid-latitude site, and thus provided no evaluation for an overhead plasmasphere. Data from the 1998 Ascension Island campaign then were used for further development. The corrected geomagnetic latitude for this site is similar in magnitude to that of Prince Sultan Air Base (PSAB) in Saudi Arabia, which was projected to be the first operational site for the extended bias calibration method. However, the Space Environment Network Display deployment was redirected to Ascension Island so this investigation was directly applicable to the revised deployment.

An evaluation of parameter values characterizing the plasmasphere structure and its density distribution is being conducted, with the principal criterion being the associated diurnal profile for the ionosphere. The relative satellite biases also were used for this evaluation because these can be compared to values derived for a mid-latitude site that is relatively unaffected by the plasmasphere.

Many variations for the plasmasphere model slant TEC were examined, including changes both in the formulas characterizing the slant TEC distribution and in the parameters implemented in those formulas. The Gallagher model was re-examined to derive appropriate parameters for a Chapman approximation and to calculate the plasmaspheric slant TEC for great-circle scans across the sky. Although it was possible to obtain slant TEC profiles similar to those for the Gallagher model using the plasmasphere parametric model, these profiles did not produce the best results for the test-case data from the 1998 Ascension Island campaign. Instead, the plasmaspheric slant-TEC contribution appeared to sustain steady levels from equatorward to overhead, and then decrease more rapidly poleward, as displayed in Figure 4. A second unexpected feature was that better results were obtained for nearly constant slant-TEC contributions for east-west scans, in contrast to the typical slant factor variation expected from a plasma layer representation.

A significant ambiguity for the bias and plasmasphere determinations was found to occur for many of the parameter selections producing the best results. In this circumstance, a non-zero baseline level for the plasmaspheric slant-TEC contribution could be re-interpreted as a receiver bias contribution with a different associated plasmaspheric slant-TEC distribution. An algorithm was developed that can determine the geometric parameters of the plasmasphere model representation for a designated partitioning of the baseline portion of the plasmaspheric TEC contribution. The ionospheric equivalent vertical TEC profiles are quite similar for these associated cases. A better formulation of the plasmasphere model is needed, but the specific requirements to be imposed for this formulation currently are unclear.

The lack of a diurnal variation for the plasmasphere model is another feature that needs improvement. This need was established by performing a calibration for the first ten hours of the day, then utilizing these derived ionospheric TEC values as reference data in performing a calibration for the second portion of the

day. A more consistent composite ionospheric TEC profile is obtained with distinctly different plasmaspheric contributions. A method of incorporating a diurnal variation using Fourier components has been formulated, but further analysis and development of the approach must be conducted before it can be evaluated.

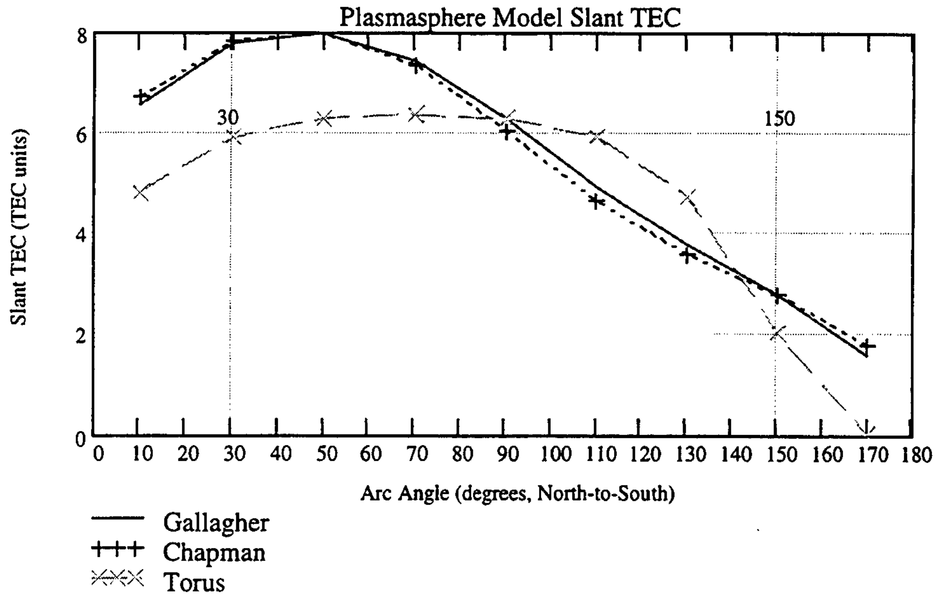

Figure 4. Comparison of plasmaspheric slant-TEC profiles for great-circle scans through local zenith. "Torus" is a parameterized toroidal model used for bias calibrations.

2.15 Space Environment Network Display (SEND)

The Space Environment Network Display initiative is a coordinated deployment of a Digital Ionospheric Sounder System (DISS), a Scintillation Network Decision Aid (SCINDA) system, and an IMS to provide near-real-time data to 55 SWXS for the generation of displays of ionospheric conditions in the vicinity of the deployment site. PRISM has been incorporated with this data system to generate ionospheric density profiles based on the real-time data and to provide evaluation information to the fielded sensors. The ionospheric density profiles from PRISM are used also for high-frequency transmission ray-tracing calculations, which ultimately are displayed as maps of accessible transmission regions in the vicinity of the SEND site. NWRA supported the deployment of the fifth IMS for SEND, its integration with the other SEND sensors, the integration of the IMS data for PRISM, and on-site operations during the demonstration period from 27 March 1999 to 21 April 1999.

NWRA personnel participated in SEND planning meetings at Hanscom in October and November 1998. These meetings covered the conditions for the initial SEND demonstration, conducted at Hanscom in January 1999, the site survey at Prince Sultan Air Base (PSAB), Saudi Arabia, conducted in November 1998, and the data interface requirements for PRISM. An RTM notebook PC system with an Ashtech receiver and antenna were prepared and provided for the PSAB site survey, but preliminary review of the system following the site survey indicates that no GPS data were recorded.

A program was developed to convert data from IMS archive files into a format suitable for use by PRISM. Additional automated procedures were developed to perform this data conversion and transmit the appropriate file to the computer system running PRISM. The PRISM computer initially resided at AFRL at Hanscom, but was transferred to 55 SWXS in January 1999 for subsequent operations.

A demonstration of SEND operations was conducted at Hanscom beginning on 22 January 1999. The IMS GPS antenna was mounted on the Digital Ionospheric Sounder System antenna tower, which then was hoisted into position. The IMS itself was moved as a fully assembled unit from its laboratory area to the nearby field trailer housing the Digital Ionospheric Sounder System and Scintillation Network Decision Aid computer systems. Final network connection and system configuration assignments were implemented, but difficulties were encountered with some of the network transmissions from the IMS-Net PC, so the network card was replaced, and transmissions were enabled. The demonstration ended on 5 February 1999, with the systems demonstrating the capability of sustained data delivery to 55 SWXS using the SWN.

After the demonstration, the IMS, with the Companion PC and IMS-Net PC, was configured for relocation to PSAB. The housing of the GPS antenna was shattered when the Digital Ionospheric Sounder System antenna tower fell during the later stages of its dismantling, due to a broken anchor mount. The GPS antenna itself suffered only minor physical damage and no electrical damage, as ascertained by a short testing period. A replacement housing was obtained quickly. All of the IMS equipment was delivered for shipment to Saudi Arabia, although the deployment destination subsequently was changed to Ascension Island. The SEND equipment was shipped to Florida around 16 March 1999 for a flight to Ascension Island.

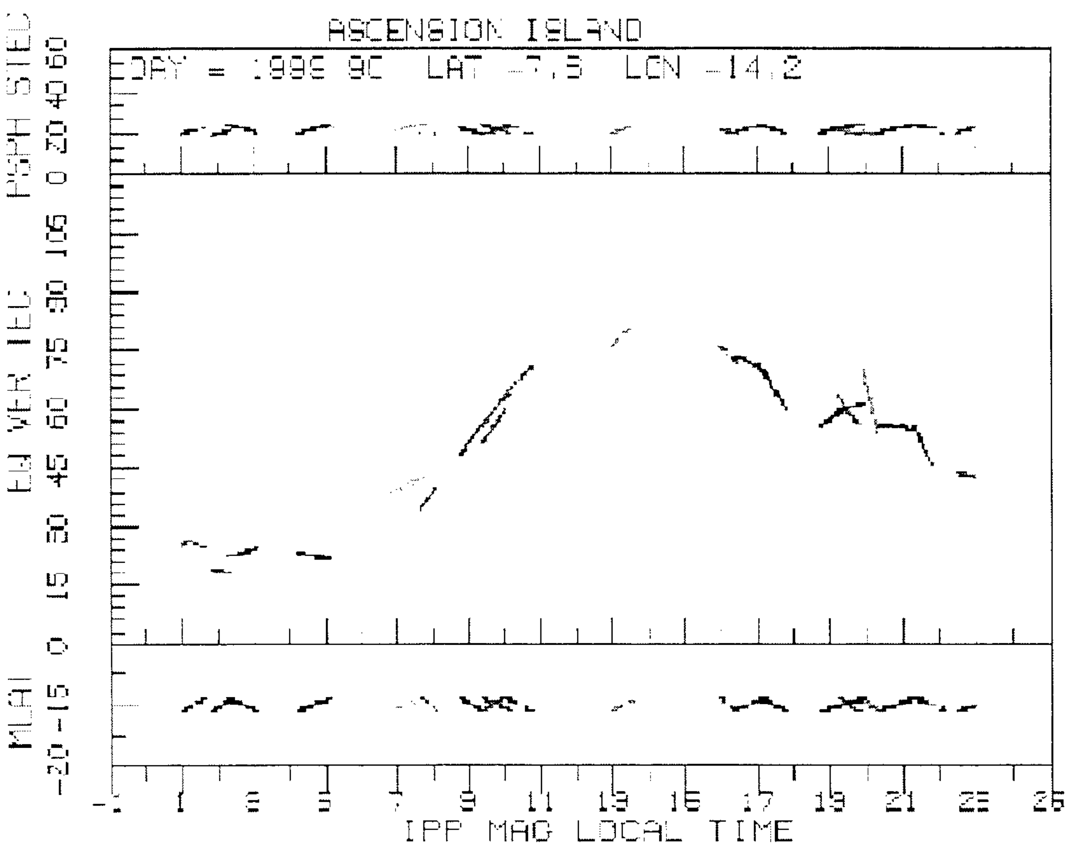

Figure 5. Bias calibration with plasmasphere determination for Ascension Island for 30 March 1999, showing diurnal ionospheric profile at magnetic latitude of site.

Intermittent operation of the IMS occurred during the initial days of the demonstration due to a need to reposition the antenna on the roof of the building containing the IMS. A problem involving the SCSI connections for the IMS UNIX systems was encountered and resolved, and occasional network problems were encountered for transmissions from Ascension Island, but normal operations of the IMS prevailed. Calibrations were performed using the extended bias calibration technique for estimating the plasmasphere contribution. A supplementary process was incorporated to compensate for the plasmaspheric TEC contribution when reporting the ionospheric measurements to the PRISM processor at 55 SWXS. Because the plasmaspheric TEC contribution can vary on a daily basis, calibrations were performed each day, but new values were installed in the IMS only when the plasmasphere change or bias shift were significant. A sample of the ionospheric and plasmaspheric TEC results from a calibration is displayed in Figure 5.

Provisions for monitoring the data transmissions from Ascension Island to Hanscom were established soon after the network capabilities were activated, with additional provisions for display of the individual and cumulative data transmissions. Similar display capabilities were established for the on-site PCs for use during the demonstration period. Considerable variations of the equivalent vertical TEC diurnal profiles from the reference monthly PIM profile were noted with considerable day-to-day variation of the equatorial anomaly effect.

A day of particular interest during the demonstration period was 6 April 1999. Scintillation was detected during the evening, and the ionospheric profile, as displayed in Figure 6, demonstrates the occurrence of both the equatorial anomaly and TEC depletions. Preliminary intensity and phase spectra for a selected interval demonstrated the utility of the 2-Hz data from the IMS. Detailed IMS archive data files for this date, as well as for the other days of the demonstration period, were copied to local disks from tape for further analysis and were transcribed to duplicate sets of CDs for archiving.

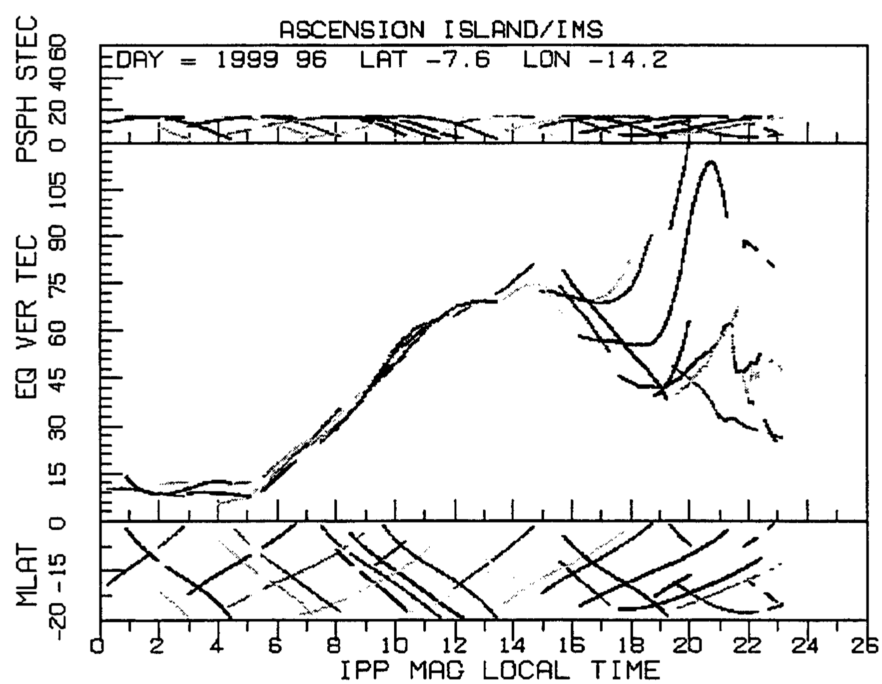

Figure 6. Case study day at Ascension Island showing equatorial anomaly at magnetic local times after 18 hours and depletion occurrence after 21 hours.

2.16 Thule GPS Data from Previous Solar Maximum

Single-channel GPS data, as recorded from an STEL 5010 GPS receiver, from the previous solar-maximum period (1987 – 1992) are stored at AFRL and have been partially transcribed from magnetic tape to CD-ROM. Existing data processing programs for these data were reviewed and documented to allow processing by AFRL personnel for both the existing data sets and those yet to be transcribed from tape.

A new program to plot the detailed 20-Hz differential carrier-phase data was developed and documented. All previous displays of the single-channel data had used six-second averages or maximum and minimum values over five-second intervals.

3. HAARP Topics

Under HAARP, an observatory is being constructed in Gakona, AK, to conduct upper-atmospheric, ionospheric, and radio-propagation research. In addition to a high-power HF transmitter being installed by Advanced Power Technologies, Inc. (APTI), NWRA is facilitating installation of an array of geophysical diagnostic instruments. During this report period, NWRA's HAARP activities involved several of these diagnostics, as well as coordination with other researchers, with APTI, and with the interested general public, as described in the following subsections.

3.1 Digisonde

The HAARP Digisonde performs a sounding of the ionosphere every 15 minutes and records the data in Standard Archiving Output (SAO) files. It also creates a Graphical Interchange Format (GIF) file that puts the data in a graphic image, the latest of which can always be found on the HAARP web site. Tyler Wellman, an entering freshman at Brown University, worked at Gakona during the summer of 1999 as an NWRA Student Intern. With guidance from Dr. Helio Zwi, of APTI, Mr. Wellman created a C program that converts the SAO files into network Common Data Format (netCDF) files.

3.2 Riometer

A 30-MHz classical riometer is operating at Gakona for measurement of radiowave absorption. During this year, NWRA Consultant Jens Ostergaard continued to improve its operation and procedures for use of data therefrom, including derivation of seasonally adjusted quiet-day curves. Initially, twenty quiet days were selected from raw data covering almost two years of operation at Gakona, each associated with a number of adjacent, and not totally quiet, days. The limited number of quiet days available illustrates the high level of daily activity at this auroral location.

We anticipated that the solar elevation at D-layer heights would be a predominant parameter controlling the seasonal variation of the quiet-day curve. This hypothesis was tested by correlating the solar elevation at heights in the interval from 60 to 120 km with the quiet-day curves. No significant correlation was found over the course of the year. Some months show the variation of the quiet-day curves to be a function of the solar elevation angle, some months show no correlation at all, and some months show the variation to be a function of the solar zenith angle! Note that the solar elevation angle is constant throughout the year for a particular sidereal time. At this particular time, the quiet-day curves varied as much as at any other sidereal time. This result was surprising. On first thought, an interpretation might be that solar elevation control of D-region absorption during quiet conditions is very small compared with other mechanisms in accounting for the seasonal variation of the quiet-day curve.

Since stellar noise is constant throughout the year, however, we examined higher layers of the ionosphere, particularly the F region, for possible effects on the seasonal variation of the quiet-day curve.

Subsequently, Mr. Ostergaard employed records selected from 18 quiet days distributed throughout the year to derive seasonally adjusted quiet-day curves. During a visit to Gakona, he installed new data-acquisition and storage software, including software for computing seasonally adjusted quiet-day curves for all days of the year. The software derives two sets of quiet-day curves and the associated absorptions. One set is based on the quiet-day curve for 27 December, which represents the lowest level of absorption throughout the year. The other set is based on the seasonally adjusted quiet-day curves. Both sets are stored on the data server at Gakona for on-line presentation on the HAARP web site. An option has been implemented to switch displays between the two sets of curves on the riometer data-acquisition computer at Gakona.

A new, armored cable was laid between the operations center and the riometer pad. New power supplies were installed for both the riometer and its GPS timing receiver. The riometer was calibrated with a noise source, and a high-pass filter was inserted in the antenna cable to eliminate RF interference experienced when the HAARP transmitter operates.

3.3 GPS Receiver for Measuring Absolute TEC

An Ashtech Z-FX CORS, consisting of a 12-channel GPS receiver and a choke-ring antenna, was purchased in December 1998 for testing at Hanscom and deployment to HAARP. A computer and associated peripheral equipment also were acquired and configured for data collection, data archiving, network communications, and autonomous restart. Power-control features within the computer thwarted the autonomous restart, so operations were migrated to a different computer. Some modifications to an ancillary program for controlling the heartbeat generation and rebooting were required because of changes in the vendor's program. Successful implementation of these control features was achieved with assistance and software modifications by the Heartbeat vendor.

Data acquisition from the Z-FX CORS is performed by the RTM program in a manner similar to that used for the RTM deployed to the Shetland Islands. High-rate (1-Hz) intensity and phase data are collected from both GPS frequencies, and low-rate (1 sample/minute) data are collected for differential group delay and differential carrier phase, with scintillation index also being recorded once per minute. These data are stored as RINEX files, for post-processing and future analysis. The RTM data collection has been supplemented by a real-time process to convert one-minute reports from the RTM program into IPP databases, which become the source of calibrated measurements of absolute TEC to be displayed on the HAARP web site.

Tests of system operations and data quality were conducted at Hanscom for about two weeks, after which the system was shipped to NWRA at Bellevue, WA, for familiarization and further testing. The system was deployed to Gakona on 22 February 1999, and remote monitoring capabilities from Hanscom were established. A joint effort was carried out by NWRA personnel at Bellevue and Hanscom to convert data from the IPP databases into calibrated TEC values in Network Common Data Format. Existing software was augmented at Hanscom and is being used for acquiring data from the IPP databases.

Software was developed at Bellevue for on-line display of TEC and the GPS observing geometry and was placed on the HAARP web server by APTI and Office of Naval Research personnel. For each UTC day, slant TEC is shown in a collection of 24-hour time-series plots, one plot for each GPS satellite (PRN#), along with the elevation angle of that satellite as viewed from Gakona. An example of the multi-satellite plots appears in Figure 7a. Beneath the time-series panels, a polar-coordinates plot shows the azimuth and elevation of all GPS tracks observed from Gakona during the day, as illustrated in Figure 7b.

Note that GPS satellites can be viewed to the south from Gakona up to elevation angles of about 80° and low to the north (over the pole) up to an elevation angle of about 20°. The orbital inclination of GPS precludes measuring TEC in the region overhead and immediately northward of Gakona; that region could be covered by means of a receiver placed farther north in Alaska.

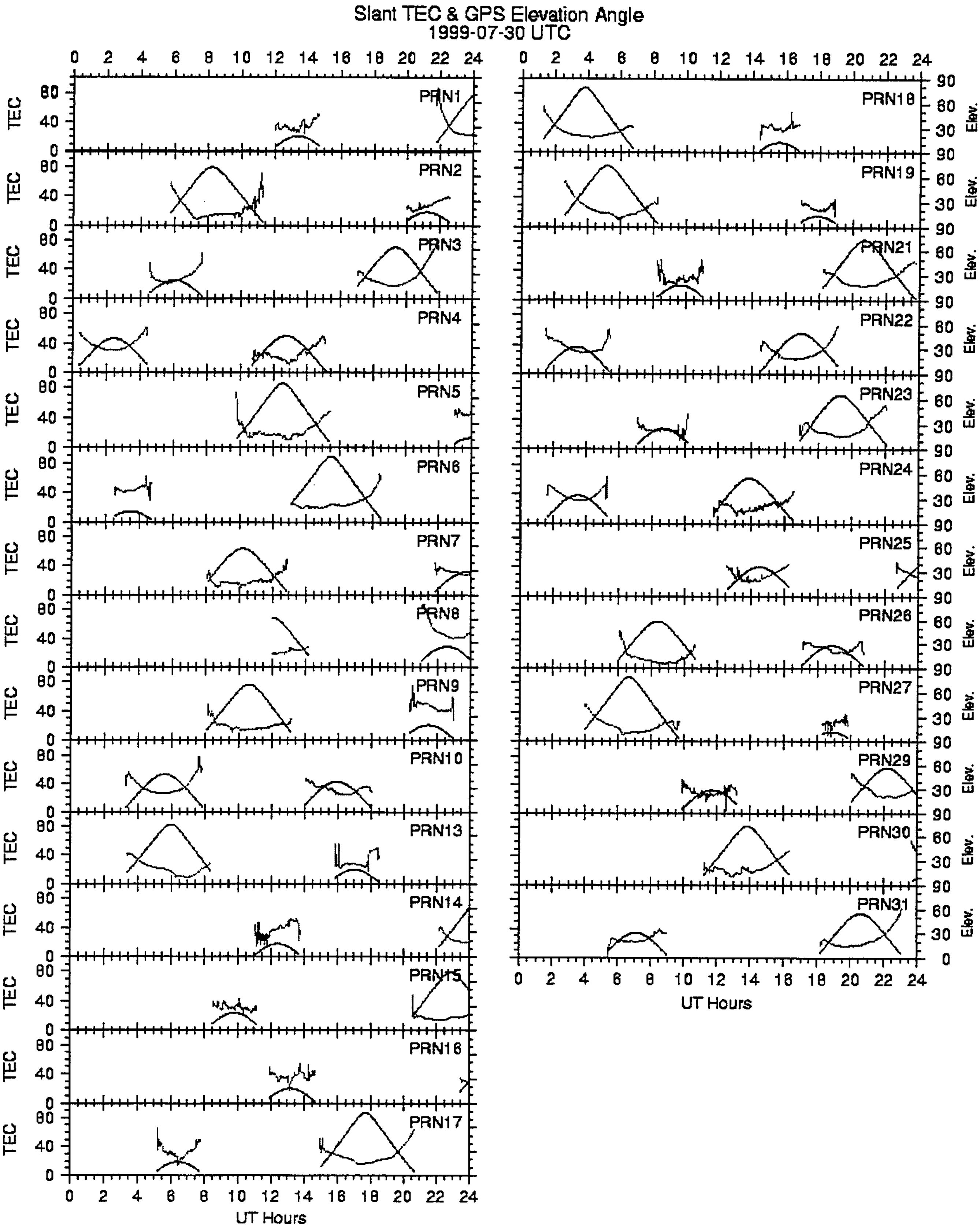

Figure 7a. Example of GPS-based slant-TEC display posted on the HAARP web site for each 24-hour period.

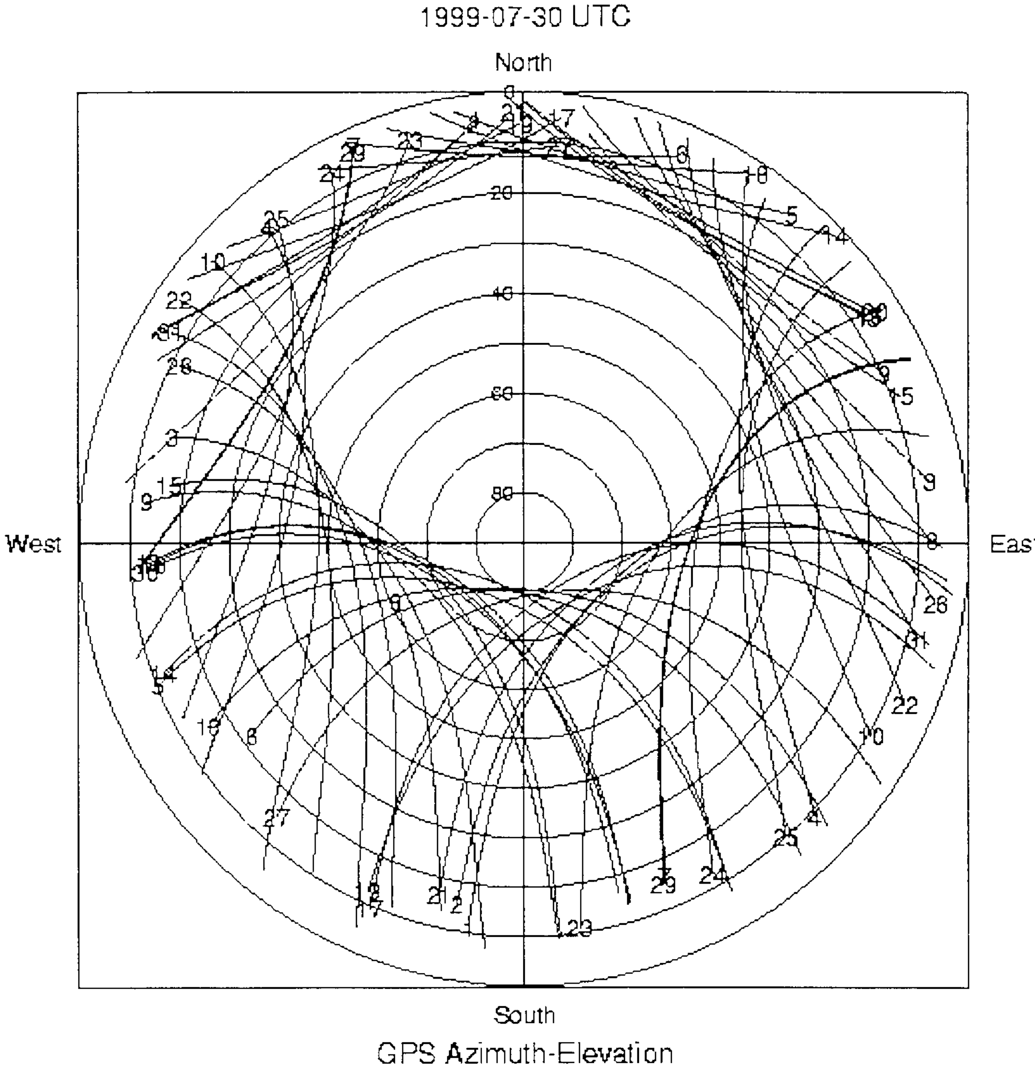

Figure 7b. GPS observing geometry posted on the HAARP web site for the observations shown in Figure 7a.

In late June 1999, the internal phase-discontinuity correction capabilities of the RTM program were activated at HAARP after preliminary testing at Hanscom, and the TEC data were examined to evaluate the benefits or problems posed by this setting. The initial performance at HAARP was encouraging, but this was a period of low ionospheric activity.

Three distinct data files are generated by the RTM program, as shown in Figure 8. The GPS RINEX file contains phase values and signal intensities for the two GPS frequencies, recorded once per second. These can provide information about scintillation. The Average RINEX file contains the Differential Group Delay, Differential Carrier Phase, and Intensity Scintillation Index (S4), recorded once per minute. The Group Delay and Carrier Phase data are used for determining bias calibrations in post-processing, using the SCORE technique, while the S4 values can be used for surveys of scintillation occurrence. The RTM Data file contains a one-minute "snapshot" of the Differential Carrier Phase referenced to the Differential Group Delay, Azimuth, and Elevation, for each visible satellite, and is re-written with current data every minute.

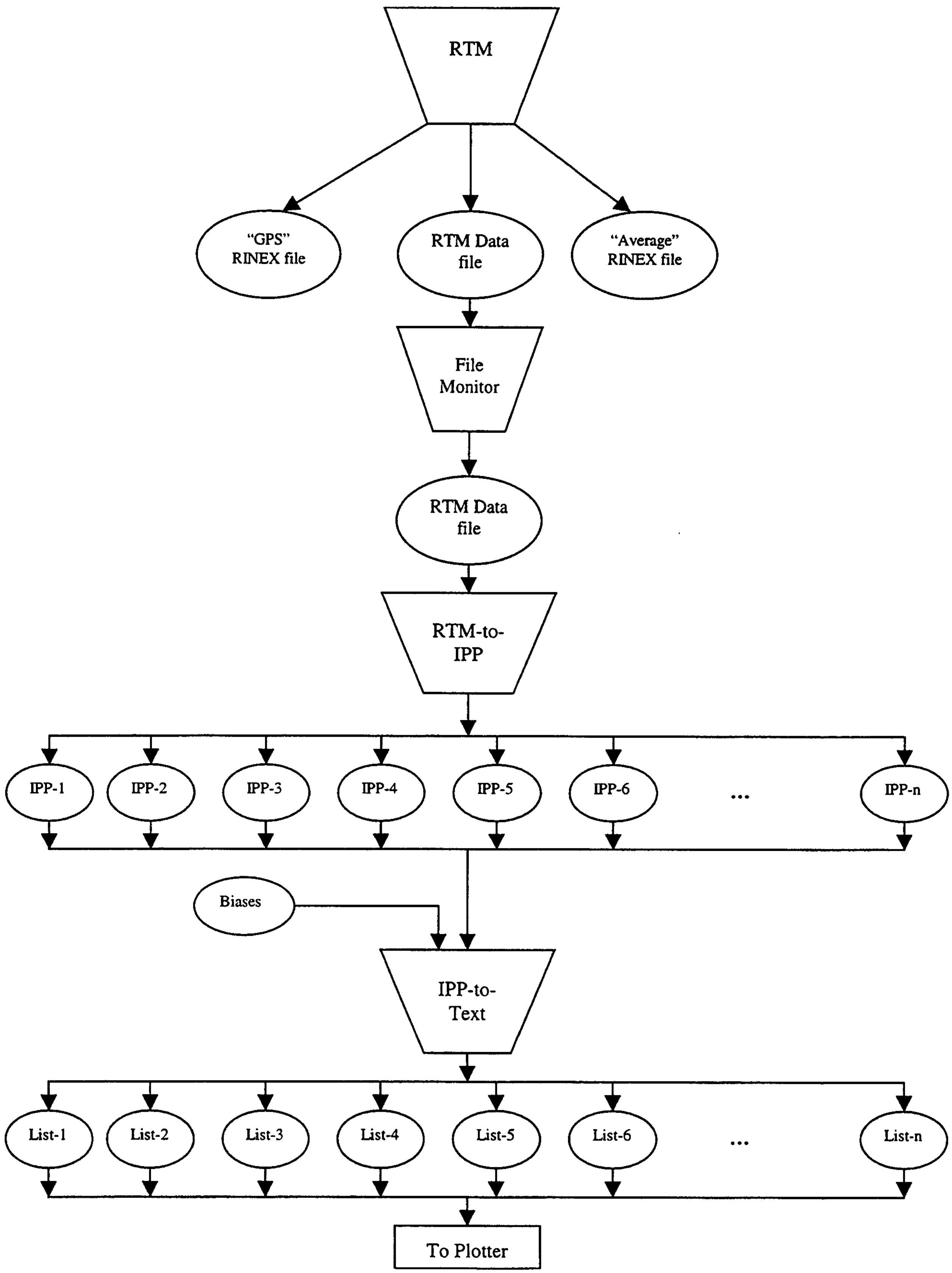

Figure 8. On-site data processing diagram for the HAARP RTM system.

It is also possible to include group-delay values in the GPS RINEX file, to calculate detailed time sequences of position estimates. Inclusion of the values and implementation of this processing have been deferred, however, pending examination of some capabilities of the RTM program for partitioning the RINEX files.

The "File Monitor" program (indicated in Figure 8) runs on a continuing basis, but with an adjustable dormancy period to minimize the use of computer system resources. It checks for creation of an RTM Data file, then transfers this file to a secondary directory and initiates its further processing. The principal action performed by this processing is to convert the RTM measurements into IPP records in files denoted as ionospheric penetrationpoint databases (IPPDBs). One IPPDB is developed for each GPS satellite pass, with allowance for a gap of up to 45 minutes during a pass.

The File Monitor program plays a secondary role of maintaining data continuity, in that it can invoke the Heartbeat re-booter to perform a full power reset of the computer and receiver if no RTM Data files are generated for a period of six minutes. Absence of RTM Data files usually results from a transmission fault on the serial line connecting the receiver and computer, halting data transmissions to the computer.

After each IPPDB is completed, a supplementary process is performed to generate a text file of the data records, using the current bias values associated with each GPS satellite to calculate slant and equivalent vertical TEC values from the measurements. At the end of each daily data-collection period (approximately 0600 Universal Time), all of the data listings are collected for transfer to the plot preparation system (Maestro). Following this transfer, the TEC and geometry data illustrated in Figure 7 are posted to the HAARP web site for the preceding Universal Time day. The two RINEX data files and all of the IPPDBs also are collected into a compressed file for transmission to AFRL, and we expect to augment this process with additional archiving of these files at HAARP

Automated procedures for processing the IPPDB's into listings suitable for conversion to Network Common Data Format were revised, with the objective of allowing future development of interim updates for the absolute TEC display instead of only once each day. Other file maintenance and processing procedures also were revised to improve performance and reduce manual maintenance operations, including network transmission of a daily archive file from HAARP to AFRL at Hanscom. This latter process required some refinement to accommodate situations when the complete network link from HAARP to Hanscom is not maintained at the scheduled time of data transmission. A "handshaking" transaction accompanies the data transmission, and a retry of the data transmission is performed if the handshaking transaction is not successful.

Provisions were developed to generate monthly vertical-TEC profiles for the HAARP site using PIM. These plots are used as references in evaluating the daily vertical-TEC profiles generated from the data collected at HAARP. For the summer months of 1999, the PIM TEC levels appear lower than the measurements, and the diurnal PIM profile appears much flatter.

Diagnostic data from the Ashtech Z-FX receiver were collected using the RTM program and delivered to Applied Research Laboratory for evaluation of a problem manifested as large and frequent RINEX "Nav" files. This condition appears to be intrinsic to the Z-FX receiver and indicates a slight mismatch between the Z-FX receiver and the RTM software, which was developed for the Ashtech Z-12 receiver. A further review of the Z-FX command instructions and responses will be needed to resolve this condition completely, but the current treatment of the problem is to continue the automated file deletion process that has been instituted.

Data collection by the RTM program at HAARP appeared to be encountering frequent interruptions and restarts for the RINEX files during July 1999. The problem appeared to be associated with "GPS

Week Rollover" and Year 2000 testing being performed using some of the extra satellites in the GPS constellation, and ended after this testing was concluded.

The revised RTM program that overcomes the "GPS Week Rollover" problem was installed at HAARP on 23 August 1999 and functioned normally. The provisions for 20-Hz data collection, using the Z-FX receiver instead of a Z-12 receiver, were invoked, but the Z-FX receiver does not appear to support the collection of 20-Hz data.

3.4 Transit Receivers for Recording Latitude Scans of Relative TEC

An NWRA ITS10S coherent radio receiving system is operating at Gakona to record differential (dispersive) phase between the mutually coherent VHF and UHF signals transmitted from Transit satellites in the Navy Ionospheric Monitoring System (NIMS). The differential phase recorded at 50 samples per sec (sps) during passes of approximately 15 minutes duration provides latitudinal scans of relative TEC over Alaska, smoothed to one sample per second and referenced to the minimum value recorded during the pass. An example of such a TEC record and its attendant geometry was presented in R&D Status Report 6.

The ITS10S originally was designed to receive signals in the "operational" band employed by the Transit satellites. It is capable also of receiving signals from the Transits' "maintenance" band (the two bands being slightly offset in opposite senses from the nominal frequencies of 150 and 400 MHz), but switching from one band to the other requires manual re-tuning. In Navy Ionospheric Measuring System operation, the individual Transits are switched from time to time between the two bands. To increase the number of signal sources readily available to the ITS10S, Research Engineer J. Francis Smith has designed a frequency-agile sweep circuit that will permit reception of signals in both bands without manual re-tuning. A board containing the new sweep circuit was fabricated and tested successfully at Bellevue, and it has been installed permanently in the ITS10S operating (for development purposes) there.

Two copies of the successfully tested board containing the frequency-agile sweep circuit have been constructed. Mr. Smith will install one in the receiver presently operating at Gakona during a trip to Alaska in September. The second has been installed in an ITS10S to be deployed, during the same field trip, at the Silver Fox Roadhouse located near Delta Junction, AK. This second ITS10S will operate in conjunction with the one at Gakona and a Transit receiver being operated at Cordova by the Naval Research Lab (NRL). These three sites form a favorable (albeit very short) chain for performing (rudimentary) tomographic imaging of plasma-density structures in the sub-auroral ionosphere via inversion of TEC records obtained there.

Tomographic imaging requires an accurate common time base for records from the various receivers in the chain. At Gakona, temporal accuracy to ± 5 msec is available on the HAARP computer network. For synchronization of the ITS10S to be deployed to Delta Junction, we have installed a GPS-based clock in its on-line computer.

The Ionospheric Tomography System (ITS) inversion software developed by NWRA was created for use with relative TEC data such as that available from the ITS10S and Naval Research Laboratory Transit receivers. Research Scientist James Secan has modified it to permit assimilation of other information about ionospheric plasma density, such as direct measurement by means of in situ probes (such as that carried on DMSP satellites) and/or true-height profiles obtained from ionosondes.

Mr. Smith has designed an improved pre-amplifier configuration for the ITS10S. It consists of low-noise VHF and UHF pre-amplifiers to be mounted at the antenna and employs a single low-loss cable to

carry both RF signals from and DC power to the pre-amps. The configuration was tested at Bellevue, presently is in use there, and will be deployed to Gakona and Delta Junction in September.

The Transits radiate by means of circularly polarized antennas. Because of inconsistencies in polarization sense between different classes of Transits, the ITS10S thus far has employed a linearly polarized receiving antenna. The only remaining class of Transit is the Oscar class, however, it is now feasible to convert the ITS10S to circular polarization. More importantly, at least some new beacon satellites being developed by Naval Research Laboratory (including one, ARGOS, already launched) will transmit with linear polarization. If the ITS10S were to receive those signals with a linearly polarized antenna, deep signal fades would be encountered due to Faraday rotation. Accordingly, all ITS10S receivers are being outfitted with simple turnstile antennas matching the circular polarization sense transmitted by the Oscar class Transits.

We have also performed comparison tests of a VHF/UHF pair of quadri-filar helix ("volute") antennas formerly used with the Transit satellites in operation of the (now decommissioned) Navy Navigation Satellite System and loaned to us by Dr. Paul Bernhardt of Naval Research Laboratory. Our tests have verified that the volute provides superior performance at low elevation angles (below ten degrees). Except for their greater cost of fabrication, we would employ them instead of turnstiles. Should any surplus volutes become available, we would field them; meanwhile, we must return the one we used for testing to Naval Research Laboratory.

From computer simulations, we have found that integration through images obtained by tomographic inversion of relative TEC records, such as those obtained along slant-paths by means of the NWRA ITS10S and the Naval Research Laboratory Transit receivers, yields quite accurate latitudinal scans of absolute vertical TEC. In the absence of such images, the conversion from slant-path to vertical TEC relies upon an ad hoc assumption, usually that of a slab-like ionosphere. Even with such an ad hoc assumption, one needs additional information to account for the unknown offset inherent in records of relative TEC (stemming from the $n\pi$ ambiguity in the dispersive phase actually measured). We are exploring measurements of absolute TEC on GPS paths near the locus of Transit-path intersections with the ionosphere as sources of such information.

A process for calibrating the Transit passes against the dual-frequency TEC measurements performed by the HAARP Ashtech GPS receiver is under development. The process utilizes the SCORE technique used to calibrate the Ashtech measurements, but it treats the Ashtech measurements, with bias values obtained from a previous calibration, as known TEC values and considers only the Transit relative TEC measurements as uncalibrated. In this analysis, the Transit reference-phase ambiguity plays the same role as an unknown bias for the dual-frequency SCORE analysis. The capability for using a selected set of TEC measurements as reference values already is implemented in the SCORE software, and development has been accomplished for reformatting the Transit data into a compatible tabular structure and constructing the appropriate processing scripts.

The initial investigation of Transit calibration using GPS reference data was performed for ITS10S data collected at Bellevue, WA, with a nearby National Oceanic and Atmospheric Administration CORS system at Robinson Point providing the GPS reference data. The Transit scan of equivalent vertical TEC is displayed in Figure 9. Despite the latitudinal variations in the Transit measurements, these equivalent vertical TEC values were all within three TEC units of GPS equivalent vertical TEC measurements at corresponding latitudes and local times.

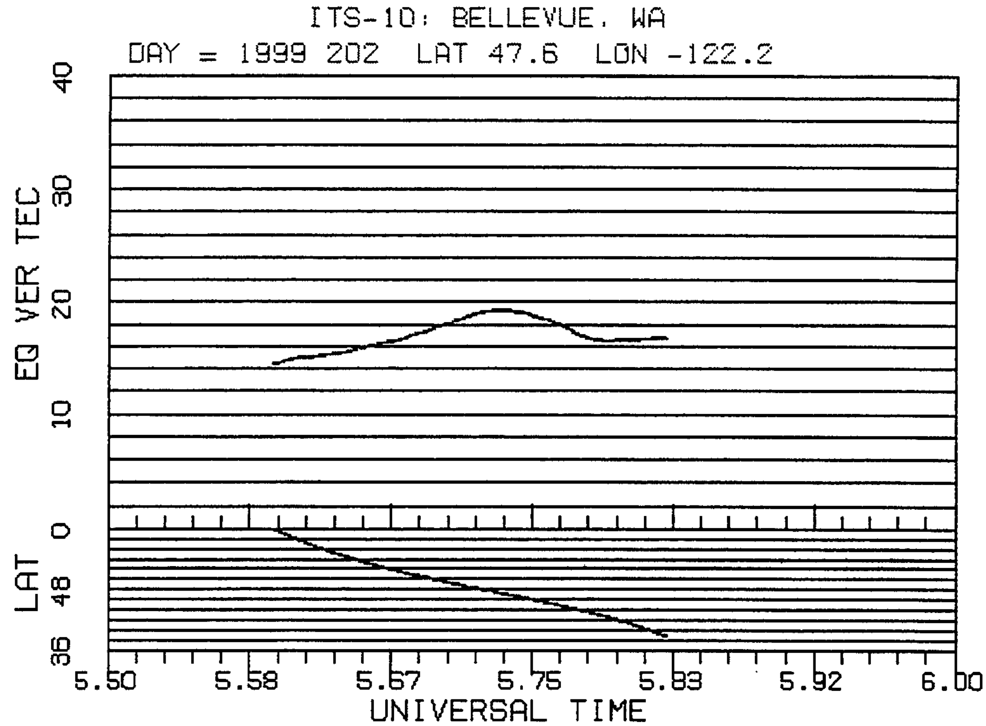

Figure 9. Transit pass over Bellevue, WA, calibrated using GPS TEC measurements as reference data.

Transit calibrations at HAARP have not been equally successful as the test case at Bellevue. Initially, the same geographic IPP coordinate system utilized for Bellevue was used at HAARP, but the resulting equivalent vertical-TEC scan displayed considerably greater variability than the GPS TEC measurements, including a negative excursion in TEC. Because the diurnal TEC gradients for the GPS data were significant at the time of this Transit pass, a potential mismatch in ionospheric coordinates could have a detrimental effect, so the calibration was repeated in geomagnetic coordinates. As in the case of the plasmasphere calibrations, the geomagnetic coordinates were derived from a dipole fit to the local corrected geomagnetic coordinates. The result was not significantly different from that using geographic coordinates. Another trial Transit calibration for a different Transit pass produced slightly better results, but the Transit TEC variation again appeared to be considerably greater than that of the GPS data. Further investigation of this discrepancy is required.

3.5 Scientific Collaboration on Diagnostics

Dr. Brett Isham, Associate Professor at Interamerican University of Puerto Rico, spent the summer of 1999 as an NWRA consultant working with the HAARP group in the Ionospheric Hazards Branch of AFRL at Hanscom. Dr. Isham has extensive expertise in radar observations of the ionosphere, particularly in high-power HF wave-interaction experiments, for which HAARP is an ideal instrument. In early July, Dr. Isham joined Dr. Keith Groves and engineer Jake Quinn, both of AFRL, for the first test experiments of the newly expanded, one-MW HAARP antenna array. For that experiment Dr. Isham reconfigured the HAARP Digisonde, which is a low-power HF radar, to take X-mode radar spectra of the irregularities created during HAARP O-mode transmissions. These measurements supplemented spectra of stimulated electromagnetic emission (SEE) and ionospheric scintillation recorded by Dr. Groves and Mr. Quinn. Simulated Electromagnetic Emission is sensitive to irregularities in the scale-size range of one to ten

meters, and scintillation is sensitive to the hundred-meter irregularity range. The X-mode observations are intended to bridge the gap, as they should be sensitive primarily to structure on a scale of tens of meters. Drs. Isham and Groves currently are analyzing the data, with results expected to be available this fall.

Dr. Isham devoted additional time to furthering the analysis of data taken in collaboration with Groves, Quinn, and others in northern Scandinavia in 1998, and to publishing the results of earlier experiments devoted to Langmuir turbulence and transition to the irregularity regime. These results show for the first time that cavitating Langmuir turbulence, known to occur in mid-latitude HF experiments at Arecibo, also occurs in high-latitude experiments. This is important for improving our understanding of the processes of irregularity generation during HF experiments at facilities such as EISCAT and HAARP.

3.6 Broader Scientific and Educational Collaboration

As Coordinator of the 1999 RF Ionospheric Interactions Workshop, Mr. John Rasmussen, NWRA consultant, prepared text and vugraphs for the Workshop Proceedings and delivered them to Hanscom AFB for printing by AFRL, along with a distribution list and mailing labels. He also prepared a report summarizing workshop attendance statistics, participant comments, and financial status. Dr. Richard Brandt has agreed to serve as the future workshop coordinator, starting with the 2000 program. Mr. Rasmussen continues to provide support to Dr. Brandt in developing the program and logistical arrangements for the 2000 workshop.

Dr. Spencer Kuo, of the Department of Electrical Engineering at Polytechnic University in Farmingdale, NY, also spent the summer at Hanscom as an NWRA consultant. He collaborated with Drs. Keith Groves, Paul Kossey, and John Heckscher of AFRL and with Prof. M.C. Lee, of the Massachusetts Institute of Technology, in a theoretical study of ELF and VLF wave generation in the heating-wave-modulated polar electrojet. An amplitude-modulated heating wave is known to modulate the ionospheric conductivity and, therefore, the electrojet current, effectively producing an ELF/VLF antenna. The new work indicates that a stimulated thermal instability also is excited and that this instability introduces an electron-temperature modulation more effectively than does the passive Ohmic-heating process. The thermal instability is expected to improve considerably the intrinsic efficiency of ELF and VLF wave generation by the amplitude-modulated HF heating wave. The generation efficiency and signal quality depend on the HF-wave modulation scheme. Four amplitude-modulation schemes were examined and compared.

During the summer, Dr. Kuo also investigated mechanisms for generation of HF-enhanced plasma lines (HFPLs). He found that Langmuir waves excited near the HF reflection height can grow to sufficiently large amplitudes that they cascade through a secondary instability. A paper by Drs. Kuo and Lee describing the process, entitled "On the Generation of a Broad Downshifted Spectrum of HFPLs in the Ionospheric Heating Experiments," has been accepted for publication in *Geophysical Research Letters*. The authors found that the instability products consist of a lower-hybrid decay mode and an obliquely propagating Langmuir sideband. The propagation angles of the sideband waves broaden substantially through filamentation or scattering. Ultimately, they are detected by backscatter radars as broadly downshifted HFPLs.

3.7 Educational Efforts and Public Relations

Along with Tyler Wellman, NWRA consultants Dr. William Gordon, of Rice University, and Dr. A. Lee Snyder participated in the HAARP open house held at the Gakona site on 31 July and 1 August. Repeat visitors from the surrounding community displayed considerable interest in HAARP, particularly in the serious research now becoming possible at the facility. A few foreign visitors also attended,

responding primarily to negative publicity about erroneously perceived effects of HAARP transmissions. The NWRA and other participants in the open house welcomed this opportunity for informed dialogue with such visitors.

3.8 Diagnostic Infrastructure

As a member of the Integrated Product Team (IPT) on Diagnostic Infrastructure Enhancement, Mr. Rasmussen was responsible for planning the development of facilities to support present and future diagnostic needs. This activity included development of a proposal for extending the current road 1.25 miles and installing additional instrument pads, power, and communications. Mr. Rasmussen also represented HAARP diagnostics at Program Management and Strategic Planning meetings during the year to define program needs and priorities. Instruments whose planning and implementation were coordinated by Mr. Rasmussen are identified in the Appendix.

4. Publications and Presentations

Bishop, G.J., R. Daniell, T. Bullett, S. Rao, A.J. Mazzella, and T. Denny, "An Application of PRISM to Regional Ionospheric Specification", *Proceedings of Ionospheric Effects Symposium*, Alexandria, VA, May 1999.

Coco, D.S., C. Coker, G.J. Bishop, A.J. Mazzella Jr., E.J. Fremouw, D. Howell, and C.E. Valladares, "Calibration of GPS Scintillation Measurements Using Simulated Signals," *Proceedings of Ionospheric Effects Symposium*, Alexandria, VA, May 1999.

Fremouw, E.J., "Latitudinal Scans of Total Electron Content during the Campaign," RF Ionoshperic Interactions Workshop, Santa Fe, NM, April 1999.

Fremouw, E.J., "Relative & Absolute TEC," HAARP Diagnostics Workshop, Lake Arrowhead, CA, May 1999.

Fremouw, E.J., "Ionospheric Scintillation," Session 2A chaired at *Ionospheric Effects Symposium*, Alexandria, VA, May 1999.

Lunt, N., L. Kersley, G.J. Bishop, A.J. Mazzella Jr., and G.J. Bailey, The Effect of the Protonosphere on the Estimation of GPS Total Electron Content: Validation Using Model Simulations", *Rad. Sci.*, **34** (5), 1261–1271, 1999.

Lunt, N., L. Kersley, G.J. Bishop, and A.J. Mazzella Jr., The Contribution of the Protonosphere to GPS Total Electron Content: Experimental Measurements, *Rad. Sci.*, **34** (5), 1273–1280, 1999.

Lunt, N., L. Kersley, G.J. Bishop, A.J. Mazzella Jr., and G.J. Bailey, The Protonospheric Contribution to GPS Total Electron Content: Two-station Measurements, *Rad. Sci.*, **34** (5), 1281–1285, 1999.

References

Bishop, G.J., D.S. Coco, N. Lunt, C. Coker, A.J. Mazzella, L. Kersley, Application of SCORE to Extract Protonospheric Electron Content from GPS/NNSS Observations, *Proceedings of ION GPS-97*, Institute of Navigation, Alexandria, VA, 1997.

Jursa, A.S., editor, Chapter 4: The Geomagnetic Field, *Handbook of Geophysics and the Space Environment*, Air Force Geophysics Laboratory, Hanscom AFB, CA, 1985.

Gallagher, D.L., P.D. Craven, R.H. Comfort, An Empirical Model of the Earth's Plasmasphere, *Adv. Space Res.*, **8**, 15-24, 1988.

Daniell, R.E., L.D. Brown, D.N. Anderson, M.W. Fox, P.H. Doherty, D.T. Decker, J.J. Sojka, R.W. Schunk, Parameterized Ionospheric Model: A Global Ionospheric Parameterization Based on First-principles Models, *Rad. Sci.*, **30** (5), 1499-1510, 1995.

Lunt, N., L. Kersley, G.J. Bishop, A.J. Mazzella, "The Contribution of the Protonosphere to GPS Total Electron Content: Experimental Measurements", *Rad. Sci.*, **34** (5) , 1281-1285, 1999.

Appendix

Consultant Support to the High Frequency Active Auroral Research Program Annual Report No. 2

John E. Rasmussen
and
Arnold L. Snyder, Jr.

Introduction: Consultant support to the High Frequency Active Auroral Research Program (HAARP) began in July 1996 for Mr. Rasmussen and in August 1996 for Dr. Snyder and has continued to date. The consultants have combined experience and understanding of the Department of Defense (DoD) acquisition process, facility planning, impacts on ionosphere-dependent and -affected systems, auroral and ionospheric physics, and diagnostic instrumentation for upper-atmospheric observations. This combination of skills has proven beneficial to HAARP in program planning and management and in coordination with prime contractors and subcontractors and with various elements of the scientific community. A summary follows for each of the major activities undertaken in support of HAARP by Mr. Rasmussen and Dr. Snyder during the period 1 September 1998 through 31 August 1999.

Planning and Implementation of Diagnostic Instrumentation: Mr. Rasmussen coordinated development and implementation of essentially all HAARP diagnostics, including the following instruments:

- University of Alaska, Fairbanks, tri-axial magnetometer and ELF/VLF receivers;
- Stanford University VLF remote-sensing receiver and long-wave wideband radiometer;
- AFRL's HF Sounder, HF Stimulated Electromagnetic Emissions receiver, 139-MHz coherent-backscatter radar, GPS scintillation monitor, imaging photometer, and lidar;
- 30-MHz classic riometer, in collaboration with NWRA consultant Jens Ostergaard;
- University of Maryland imaging riometer;
- Scion Associates multi-antenna satellite scintillation system;
- NWRA's measurements of absolute TEC and latitudinal scans of relative TEC;
- Naval Research Laboratory's SWIR imager.

As a member of the HAARP Diagnostic Infrastructure Enhancement Integrated Product Team (IPT), Mr. Rasmussen was responsible for planning the development of facilities to support present and future diagnostic needs. This activity included development of a proposal for extending the current road 1.25 miles and installing additional instrument pads, power, and communications. Mr. Rasmussen also represented HAARP diagnostics at Program Management and Strategic Planning meetings during the year to define program needs and priorities.

Planning and Implementation of Site Infrastructure: Dr. Snyder is serving as the Program's representative on the IPT for the Operations Center Control Room. The first attempt to define an Operations Center design resulted in an architectural cost estimate that exceeded program budgetary estimates. During 1998, an Operations Center user survey was developed and distributed. The survey resulted in definition and prioritization of the functions and approximate room sizes needed for a permanent HAARP Operations Center. Using the acquisition approach of cost as an independent variable, a second design effort was initiated and coordinated with the prime contractor and the Alaskan architectural design firm, USKH. Under a subcontract from APTI, the architectural firm prepared the bid package for a competitive source selection among five pre-qualified construction firms. The cost proposal from the low bidder (Dokoosian Construction) was within the allotted budget, and construction began in early July 1999. As the Program's representative on the Operations Center IPT, Dr. Snyder has coordinated government positions and resolved issues during construction. The Center is scheduled for completion on 10 January 2000.

Mr. Rasmussen and Dr. Snyder serve as members of the IPT for the Operations Center Control Room, with responsibility for planning its layout, furnishings, power, and communications. In collaboration with James Battis and Gene Laycock (AFRL), they developed an initial requirements list for furnishings and conducted a search for surplus furnishings that might be available at Elmendorf and/or Eielson AFB, AK. While some of the items were found, it was determined that sheltered storage space was not available at the HAARP site to collect the furniture over an extended time. APTI investigated the cost and availability of Wright Line NetView furniture for the HAARP transmitter control. This led Rasmussen and Snyder to develop a detailed list of furnishings needed and to discuss potential purchase with several Wright Line representatives. A cost proposal was received from Wright Line. Upon further investigation, it was determined that the Federal Acquisition Regulations require furnishings to be acquired from the Federal Prison Industries (FPI) unless a waiver is received. A waiver request has been submitted, and discussions with FPI are planned for December 1999. The furnishings need to be acquired and installed by April 2000 to support the move of equipment and functions from the temporary trailers to the permanent Operations Center.

Mr. Rasmussen also serves as a member of the IPT for the Operations Center Move. He is responsible for planning the transfer of operations from the temporary trailer operations center to the new facility. In cooperation with APTI, he has developed an initial plan for the installation of power, telephones, and the data network in preparation for moving transmitter control in April 2000.

A coherent aircraft-alert radar at the HAARP field site is needed for detection and tracking of general-aviation aircraft flying at low altitudes. An early study by APTI identified the AN/UPS-3 radar as potentially suitable for this task, and the United States Marine Corps (USMC) possesses a number of such radars. Mr. Laycock contacted a USMC unit in Pasadena, CA, and found they were willing to deploy a radar to the HAARP site for tests of performance and electromagnetic compatibility (EMC). Dr. Snyder developed test plans, accompanied the Marines to Alaska, arranged for a target aircraft (a Supercub), and coordinated and supervised the performance tests. Conducted in January 1999, these tests showed that the AN/UPS-3 radar reliably detects and tracks low-altitude general aviation aircraft flying in the vicinity of the HAARP site. The EMC tests will be conducted in October 1999.

At this point in development of the HAARP facility, a cleanup plan is necessary. Together

with Mr. Laycock, Dr. Snyder developed such a plan, which includes disposal of excess items. The excess items include, for example, the former antenna-matching units, diesel-electric generators, a heating boiler unit, liquid holding tanks, and potentially several or all of the ATCO trailers being used as the present Operations Center. Mr. Laycock has coordinated turn-in of the excess materials with organizations at Elmendorf AFB, AK. Site cleanup is scheduled for Spring 2000.

Coordination and Support of Scientific Research: Mr. Rasmussen and Dr. Snyder continue to assist the Program with coordination of research activities being carried out at and with the HAARP facility. Together with NWRA Consultant Jane Rasmussen, Mr. Rasmussen facilitated and coordinated the fifth annual RF Ionospheric Interactions Workshop, held during 18-21 April 1999 at the Radisson Hotel in Santa Fe, NM. These activities included the following:

- coordination with DoD and NSF sponsors and the Steering Committee;
- preparation of the agenda;
- arrangements for the facility;
- preparation and distribution of workshop announcements;
- preparation and distribution of workshop proceedings; and
- preparation of a final report to the sponsors.

Together, Mr. and Mrs. Rasmussen and Dr. Snyder prepared and coordinated the HAARP Diagnostics Workshop held during 25-27 May 1999 at the UCLA Lake Arrowhead Conference Facility, CA. Again, these efforts included coordination with HAARP management, arrangement for meeting facilities, and preparation of the agenda. Mr. Rasmussen and Dr. Snyder developed and presented the "HAARP Research Guidelines" at the workshop. This effort will be followed by collaboration with Dr. Michael McCarrick (APTI) in November 1999 to bring the guidelines to a publishable state. The guidelines include procedures for proposal submission, guidance on HAARP data rights, and procedures for requesting site-visit approval, temporary instrument installation, and operation and temporary removal of permanent HAARP diagnostic instruments.

In addition to the foregoing, Mr. Rasmussen and Dr. Snyder assisted the Program in review of proposals for experiments during HAARP field campaigns; coordinated provision of facilities for instruments, including shelter, power, and communications; and participated directly in campaigns, including performance of repairs to the HF sounder and the riometer and monitoring the aircraft-alert radar.

Public and Educational Outreach: Mr. Rasmussen and Dr. Snyder participated in planning of the yearly open house at the HAARP field site near Gakona, AK, as well as of expected visits by senior officials of DoD. These events were planned and conducted to promote program awareness, understanding, and the potential for innovative research for DoD applications. Together with Dr. Daniel Solie (University of Alaska, Fairbanks), they coordinated a luncheon seminar series presented in cooperation with the Prince William Sound Community College, Glennallen, AK. The seminar series was presented during 9-11 March 1999 in conjunction with the March 1999 Science and Applications Campaign. Dr. Snyder presented one of the three seminars, "Space Weather and Auroral Photography." He also prepared a talk, "Ionospheric Generation of Radio Waves and the

Detection and Characterization of Underground Facilities," for presentation on 2 December 1999 at the University of Massachusetts' Center for Atmospheric Research.

HAARP Program Planning: Given the nature of Congressional Initiative Programs, out-year planning is a continuing challenge, as the government may not obligate or commit funds to undertake activities that require funding from more than a single year's appropriation. This requires tailoring of activities for contractual actions to be consistent with current-year Congressional appropriations and authorizations. In addition, out-year planning is updated to structure work consistent with expected Congressional funding levels. Mr. Rasmussen and Dr. Snyder coordinated such planning with the HAARP prime contractor (APTI) and with diagnostics contractors to define realistic work packages and to update associated cost estimates, especially with regard to the Operations Center design and construction.